CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter details the market and technology assessment that the U.S. Department of Energy (DOE) has carried out in support of the ongoing energy conservation standards rulemaking for residential furnaces and residential central air conditioners and heat pumps. It consists of two sections: the market assessment and the technology assessment.

The goal of the market assessment is to develop a qualitative and quantitative characterization of both the residential furnace and the residential central air conditioner and heat pump industries and market structures, based on publicly available information and data and information submitted by manufacturers and other stakeholders. The technology assessment is a preliminary list of technologies that can improve the efficiency of residential furnaces and residential central air conditioners and heat pumps. These technologies are considered in the screening analysis

For furnaces, DOE examined publicly available information from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Consumers' Directory of Certified Efficiency Ratings for Furnaces[1], the appliance efficiency database from the California Energy Commission (CEC)[2], the appliance database from ENERGY STAR[3], and the Consortium for Energy Efficiency (CEE) Residential Natural Gas Furnaces Qualified Products List[4]. DOE consolidated these databases, eliminating all duplicate and discontinued models, into a master list of furnaces on the market, which hereinafter will be referred to as DOE's database.

For central air conditioners and heat pumps, DOE examined the equipment certification directory from the Air-Conditioning, Heating and Refrigeration Institute (AHRI), as well as Current Industry Reports (CIR) and Annual Survey of Manufactures (ASM) from the U.S. Census Bureau. Issues addressed include: manufacturer characteristics and market shares; existing regulatory and non-regulatory efficiency improvement initiatives; product classes; and trends in the equipment markets and characteristics.

3.1.1 Product Definitions

3.1.1.1 Furnaces

A residential, or warm-air, furnace is an integral part of a home's central heating and cooling system that provides heated air to the conditioned space through ductwork. A fuel-burning furnace provides which by passing the combustion products through an air-to-air heat exchanger. The furnace uses a blower to propel circulation air over the outside of the heat exchanger, transferring heat from the hot combustion gases to the cool circulation air. The heated air is then distributed via ductwork to the conditioned space, and the products of combustion are exhausted from the heat exchanger to the atmosphere through the flue passage.

The Energy Policy and Conservation Act (42 U.S.C. 6291 *et seq*.; EPCA) defines a residential "furnace" as a product that utilizes only single-phase electric current, or single-phase electric current or DC current in conjunction with natural gas, propane, or home heating oil, and which:

(1) is designed to be the principal heating source for the living space of a residence;
(2) is not contained within the same cabinet with a central air conditioner whose rated cooling capacity is above 65,000 Btu per hour;
(3) is an electric central furnace, electric boiler, forced- air central furnace, gravity central furnace, or low pressure steam or hot water boiler; and
(4) has a heat input rate of less than 300,000 Btu per hour for electric boilers and low pressure steam or hot water boilers and less than 225,000 Btu per hour for forced-air central furnaces, gravity central furnaces, and electric central furnaces. (42 U.S.C. 6291(23))

Although the definition in EPCA covers a number of different types of products, as discussed in the final rule, DOE maintained the scope of coverage from the November 2007 Rule for its analysis of amended AFUE standards, which included four product classes of furnaces (non-weatherized gas furnaces, weatherized gas furnaces, mobile home gas furnaces, and non-weatherized oil-fired furnaces). DOE did not consider amended standards for mobile home oil-fired furnaces and weatherized oil-fired furnaces because there are very few shipments of these products, such that the energy savings resulting from amended efficiency standards would be *de minimis*. DOE initially made this determination for the November 2007 Rule, and the markets for mobile home oil-fired furnaces and weatherized oil-fired furnaces have not changed. 71 FR 59204, 59214 (Oct. 6, 2006). DOE considers the opportunity for energy savings to be insignificant for these product classes due to their extremely low shipment volumes. DOE also did not consider amended AFUE standards for electric furnaces. The efficiency of these products already approaches 100 percent AFUE, and thus, the impact of amending the AFUE energy conservation standards for these products would be *de minimis.* However, DOE did consider standby mode and off mode standards for electric furnaces as described below.

This rulemaking will establish energy conservation standards for energy consumption of furnaces operating in standby mode and off mode. Section 310(3) of the Energy Independence and Security Act of 2007 (EISA 2007; Pub. L. 110-140) amended EPCA to require that energy conservation standards published after July 1, 2010, address standby mode and off mode energy use (42 U.S.C. 6295(gg)), if justified by the criteria for adoption of standards in section 325(o) of EPCA (42 U.S.C. 6295(o)). In this rulemaking, DOE intends to incorporate such energy use into any amended standard it adopts in the final rule, which is scheduled to be issued by June 30, 2011.

DOE's current standards for furnaces are expressed as minimum annual fuel utilization efficiencies (AFUE). AFUE is an annualized fuel efficiency metric that fully accounts for fuel consumption in active, standby, and off modes. DOE published a test procedure final rule in the *Federal Register* on October 20, 2010 (hereafter referred to as the October 2010 TP Rule), that amended DOE's test procedure for furnaces and boilers to establish a method for measuring the electrical energy use in standby mode and off mode for gas and oil-fired furnaces. For this rulemaking, DOE is assuming that homeowners are unlikely to switch their furnaces to off mode in the non-heating season; and therefore the power consumed in off mode is equivalent to the power consumed in standby mode. As such, DOE is issuing separate but equivalent standards for maximum standby and off mode electrical energy consumption for all furnaces covered in this rulemaking.

3.1.1.2 Central Air Conditioners and Heat Pumps

A residential central air conditioner is another important part of a home's central heating and cooling system that provides cooled air to the conditioned space through ductwork. The air conditioner uses a blower, which for split systems may be contained in the furnace, to propel circulation air over the outside of a heat exchanger (*i.e.* evaporator coil), transferring heat from warm circulation air to the cool refrigerant. The cooled air is then distributed via ductwork to the conditioned space, while a compressor is used to further raise the refrigerant temperature before the refrigerant transfers heat to the atmosphere through another heat exchanger (*i.e.* condenser coil). Split system air conditioners are comprised of an indoor unit, which contains the evaporator coil and indoor blower, and an outdoor unit, often referred to as the condenser, which contains the compressor, condenser coil, and a condenser fan to blow ambient air over the coil. Packaged systems contain all of these components in a single unit.

EPCA defines a "central air conditioner" as "a product, other than a packaged terminal air conditioner[a], which is powered by single-phase electric current, air cooled, rated below 65,000 Btu per hour, not contained within the same cabinet as a furnace, the rated capacity of which is above 225,000 Btu per hour, and is a heat pump or a cooling only unit." (42 U.S.C. 6291(21)(A)-(E)) DOE has incorporated this definition into its regulations at 10 CFR 430.2.

A residential central heat pump utilizes the same components as central air conditioner, but it also has a reversing valve. The reversing valve switches the direction of the refrigerant flow and allows for the system to provide heating during the winter months in addition to cooling during the summer.

EPCA defines a "heat pump" as "a product, other than a packaged terminal heat pump[b], which consists of one or more assemblies, powered by single-phase electric current, rated below 65,000 Btu per hour, utilizing an indoor conditioning coil, compressor, and refrigerant-to-outdoor air heat exchanger to provide air heating, and may also provide air cooling, dehumidifying, humidifying circulating, and air cleaning." (42 U.S.C. 6291(24)(A)-(E)) DOE has incorporated this definition into its regulations at 10 CFR 430.2.These products, also called unitary air conditioners and heat pumps, are limited to cooling capacities of less than 65,000 Btu/hr (5.4 tons) and do not include room air conditioners[c]

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[a] "Packaged terminal air conditioner" is defined in 10 CFR 430.2 as "a wall sleeve and a separate unencased combination of heating and cooling assemblies specified by the builder and intended for mounting through the wall. It includes a prime source of refrigeration, separable outdoor louvers, forced ventilation, and heating availability energy."

[b] ." "Packaged terminal heat pump" is defined in 10 CFR 430.2 as "a packaged terminal air conditioner that utilizes reverse cycle refrigeration as its prime heat source and should have supplementary heating availability by builder's choice of energy." For more information on package terminal air conditioners and heat pumps, see http://www.eere.energy.gov/buildings/appliance_standards/commercial/packaged_ac_hp.html.

[c] "Room air conditioner" is defined in 10 CFR 430.2 as "a consumer product, other than a 'packaged terminal air conditioner,' which is powered by a single phase electric current which is an encased assembly designed as a unit for mounting in a window or through the wall for the purpose of providing delivery of conditioned air to an enclosed

DOE's current standards for central air conditioners are expressed as minimum seasonal energy efficiency ratio (SEER) and SEER and heating seasonal performance factor (HSPF) for heat pumps. SEER is a seasonal efficiency metric that fully accounts for fuel consumption in active, standby, and off modes during the cooling season, while HSPF is a seasonal efficiency metric that fully accounts for active, standby and off modes for heat pumps during the heating season. For this rulemaking, DOE is considering energy efficiency ratio (EER) for one trial standard level (TSL) as well because this metric is part of a consensus agreement and would provide additional energy savings. DOE published a test procedure SNOPR in the *Federal Register* on April 1, 2011, that proposes to amend DOE's test procedure for air conditioners and heat pumps to establish a method for measuring the electrical energy use in standby mode and off mode for air conditioners and heat pumps during the time, which is not already accounted for in the SEER or HSPF metrics. 76 FR 18105.

3.1.2 Product Classes

3.1.2.1 Furnaces

DOE categorized the furnaces into product classes and will formulate a separate amended energy conservation standard for each product class in this rulemaking. EPCA specifies the criteria for product class separation, which includes: (1) the type of energy consumed; (2) capacity; or (3) other performance-related features, such as those that provide utility to the consumer or other features deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295(q))

Because the current residential furnaces market is very similar to the market that existed for the November 2007 residential furnaces rulemaking in terms of the types of products available, DOE continued to use the product classes established in that rulemaking. The November 2007 Rule divided products by fuel type (*i.e.*, gas, oil-fired, electric) and by performance-related features, such as whether they were weatherized (*i.e.*, intended for outdoor installation) or non-weatherized (*i.e.*, intended for indoor installation). The November 2007 Rule also considered mobile home furnaces as a separate product class due to the unique size and venting constraints that are placed on those products. Therefore, the product classes that DOE is considering in this rulemaking for amended AFUE minimum energy conservation standards are: non-weatherized gas furnaces, mobile home gas furnaces, and non-weatherized oil-fired furnaces. DOE also considered weatherized gas furnaces and electric furnaces, but determined that for weatherized gas furnaces, the November 2007 Rule set the standards at the max-tech level; and that electric furnaces on the market have efficiencies already approaching 100 percent AFUE and, as a result, have no methods available to increase the AFUE of these products. DOE will also analyze these product classes for its maximum allowable standby and off mode energy consumption standards analyses. These product classes and their characteristics are shown in Table 3.1.1.

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space. It includes a prime source of refrigeration and may include a means for ventilating and heating." For more information on room air conditioners, see http://www.eere.energy.gov/buildings/appliance_standards/residential/room_ac.html.

Table 3.1.1 Product Classes for Residential Furnaces Used in this Rulemaking

Product Class	Characteristics
Non-weatherized gas furnace	Intended for indoor installation; fueled by natural gas
Weatherized gas furnace	Intended for outdoor installation; only sold as gas/electric packaged units with air conditioners; fueled by natural gas
Mobile home gas furnace	Intended for mobile home installation; require direct vent; subject to space constraints; fueled by natural gas
Non-weatherized oil-fired furnace	Intended for indoor installation; fueled by heating oil
Electric furnace	Intended for indoor or outdoor installation; provide heat using electric resistance heating elements

3.1.2.2 Central Air Conditioners and Heat Pumps

Residential central air conditioners and heat pumps are divided into nine product classes based on physical characteristics of the product that affect performance. Key physical characteristics include product type (*i.e.*, air conditioner or heat pump), whether the unit is a single package or has individual indoor and outdoor sections, and space constraints that relate to product utility.

The existing Federal energy conservation standards for residential central air conditioners and heat pumps went into effect on January 23, 2006. 10 CFR Part 430.32(c)(2) lists the nine product classes of residential central air conditioners and heat pumps and their corresponding energy conservation standards. The product classes are:

- Split-system air conditioners
- Split-system heat pumps
- Single-package air conditioners
- Single-package heat pumps
- Through-the-wall air conditioners and heat pumps – split system
- Through-the-wall air conditioners and heat pumps – single package
- Small duct, high velocity systems
- Space-constrained air conditioners
- Space-constrained heat pumps

For this residential central air conditioner and heat pump rulemaking, DOE maintained the existing product classes. However, two of the existing product classes, through-the-wall air conditioners and heat pumps – split system and through-the-wall air conditioners and heat pumps – single package, no longer exist[d]. Therefore, DOE did not consider those two product classes separately (instead DOE considered them to be space-constrained products) and examined only

[d] As defined in 10 CFR 430.2, the through-the-wall product class applies only to products manufactured prior to January 23, 2010. This provision eliminates through-the-wall units as a separate product class after this date.

seven product classes for this residential central air conditioner and heat pump rulemaking. The seven product classes DOE examined are:

- Split-system air conditioners
- Split-system heat pumps
- Single-package air conditioners
- Single-package heat pumps
- Small duct, high velocity systems
- Space-constrained air conditioners
- Space-constrained heat pumps

3.1.3 Test Procedures

3.1.3.1 Furnaces

The energy conservation standards for residential furnaces are represented in terms of the annual fuel utilization efficiency (AFUE) as measured by the DOE test procedure. (42 U.S.C. 6295(f)(1-2)) DOE's test procedure for residential furnaces is described in Appendix N to Subpart B of 10 CFR part 430, which incorporates by reference American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ANSI/ASHRAE) Standard 103-2007 Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers. AFUE is the ratio of annual output of useful heat to annual fuel input energy, and it includes active mode, standby, and off mode fuel consumption (including non-heating-season pilot input loss if applicable).

For gas and oil-fired furnaces, AFUE does not account for electrical energy consumption in standby mode and off mode, although it does address fossil fuel use in these modes. For electric furnaces, AFUE also does not account for electrical energy consumption in standby mode and off mode. To satisfy the requirements of EPCA as amended by EISA, the DOE test procedure for residential furnaces and boilers was amended by a final rule published on October 20, 2010, to account for standby and off mode electrical energy consumption. 75 FR 64621. The amended DOE test procedure incorporates by reference provisions of the International Electrotechnical Commission (IEC) Standard 62301, "Household electrical appliances—Measurement of standby power" ("IEC 62301"). It also adds new calculations to determine the annual energy consumption associated with standby mode and off mode measured power, and it modifies the existing energy consumption equations to integrate standby mode and off mode electrical energy consumption into the calculation of overall annual energy consumption of these products.

3.1.3.2 Central Air Conditioners and Heat Pumps

The test procedures for central air conditioners and heat pumps are codified in 10 CFR 430, Subpart B, Appendix M. Most aspects of the existing test procedure for central air conditioners and heat pumps date back to its original publication in the *Federal Register* on December 27, 1979. 44 FR 76700. DOE modified the test procedure on March 14, 1988, to cover variable-speed central air conditioners and heat pumps, to address testing of split non-ducted units, and to change the method used for crediting heat pumps that provide a demand defrost capability. 53 FR 8304.

A further revision of the test procedure for central air conditioners and heat pumps was published as a final rule on October 11, 2005, and became effective on April 10, 2006. 70 FR 59122. Generally, the October 2005 final rule added new sections, revised several sections, and re-organized the test procedure in order to eliminate the need for several test procedure waivers and to make the test procedure more chronological in its progression. The revisions to the test procedure did not alter the minimum energy conservation standards in effect for central air conditioners and heat pumps. On July 20, 2006, DOE published a proposed rule to consider further changes to the test procedure in response to issues raised by stakeholders prior to the publication of the October 11, 2005, final rule. 71 FR 41320. DOE determined that it was appropriate to consider additional modifications to the test procedure for the following reasons: (1) to implement test procedure revisions that are needed because of new energy conservation standards for small-duct, high-velocity (SDHV) systems; (2) to better address test procedure waivers for multi-split systems; and (3) to address sampling and rating issues that have been raised since new minimum energy conservation standards for these products became effective on January 23, 2006. *Id*. at 41321-22. A final rule adopting additional amendments to the central air conditioner and heat pump test procedures related to these issues was published on October 22, 2007, which became effective on April 21, 2008. 72 FR 59906. Subsequent waivers granted for residential modulating multi-split systems terminated on the effective date of the latest test procedure final rule. 72 FR at 59906-07. EISA 2007 amended EPCA to require DOE to regulate standby and off mode power consumption (42 U.S.C. 6295(gg)(3)); and DOE is currently conducting another test procedure rulemaking to address off mode as well as other test procedure issues. A NOPR was published on June 2, 2010 and a final rule is slated for publication in spring 2011. 75 FR 21224-31271.

3.2 MARKET ASSESSMENT

The following market assessment identifies manufacturer trade associations, domestic and international manufacturers of residential central air conditioners and heat pumps and their corresponding market shares, and regulatory and non-regulatory programs. The market assessment also describes the cost structure for the residential central air conditioner and heat pump industry and summarizes relevant market performance data.

3.2.1 Trade Associations

AHRI is a national trade association of manufacturers of residential, commercial, and industrial appliances, equipment, components, and related products. AHRI was established in January 2008 when the Air-Conditioning and Refrigeration Institute (ARI) merged with the Gas Appliance Manufacturers Association (GAMA). AHRI's member companies are responsible for over 90 percent of the residential and commercial air conditioning and space heating equipment sold in North America.[5] AHRI develops and publishes technical standards for residential and commercial equipment using rating criteria and procedures for measuring and certifying equipment performance. AHRI also participates in developing international standards and has established a policy of adopting international standards for use in the United States when technologically and economically feasible.

AHRI administers the GAMA Certification[e] program that tests and certifies the performance of gas- and oil-fired central furnaces that use single-phase electric current or DC and that have a heat input rate of less than 225,000 Btu/h. AHRI maintains the AHRI Directory of Certified Product Performance that lists all products that have been certified by the AHRI.

AHRI also administers the ARI Performance Certified program that tests and certifies the performance of central air conditioners and heat pumps. AHRI maintains the AHRI Directory of Certified Product Performance that lists all products that have been certified by the AHRI. AHRI maintains certified performance directories for both air conditioners and heat pumps rated below 65,000 Btu/h. The AHRI directories subdivide these products based upon certain defining characteristics, such as single package or split system and coil only or coil and blower combinations. Table 3.2.1 shows the AHRI classifications where products are available in the AHRI directories of certified products, along with the corresponding DOE product classes for this rulemaking.

[e] The GAMA Efficiency Rating Certified mark is being phased out of use by January 1, 2012, and will be replaced by the AHRI Certified mark.

Table 3.2.1 AHRI Directory of Certified Product Performance Classifications for Residential Central Air Conditioners and Heat Pumps

DOE Product Class	AHRI Classifications*
Split system air conditioners	RCU-A-C RCU-A-CB RCU-A-CB-O RCUY-A-CB RCUY-A-CB-O RC-A
Split system heat pumps	HRC-A-C HRC-A-CB HRCU-A-C HRCU-A-CB HRCU-A-CB-O HORC-A-C HORCU-A-C HORCU-A-CB
Single package air conditioners	SP-A SPY-A
Single package heat pumps	HSP-A
Small duct, high velocity systems	SDHV-RCU-A-CB SDHV-HRCU-A-CB SDHV-HORCU-A-CB
Space constrained products – air conditioners**	TTW-RCU-A-C TTW-RCU-A-CB
Space constrained products – heat pumps**	TTW-HRCU-A-C TTW-HRCU-A-CB

*The classifications listed are only those with products available in the AHRI Directories of Certified Product Performance for central air conditioners and heat pumps. For more information on AHRI classifications and their definitions, visit www.ahridirectory.org/ahriDirectory/pages/fieldHelp.aspx?program=AC&controlID=ariType for air conditioners, or www.ahridirectory.org/ahriDirectory/pages/fieldHelp.aspx?program=HP&controlID=ariType for heat pumps.
**On January 23, 2010, the through-the-wall equipment classes expired, at which time, they became part of the space constrained product classes.

HARDI is an international trade organization that represents over 450 wholesale companies in the HVAC industry, including 17 international companies, plus over 300 manufacturing associates and nearly 140 manufacturer representatives. HARDI estimates that its members represent 80 percent of the dollar value of the HVACR products sold through distribution. The organization is a recent consolidation of the Northamerican Heating, Refrigeration & Airconditioning Wholesalers (NHRAW) and Air-conditioning & Refrigeration Wholesalers International (ARWI).[6]

ACCA is a nationwide trade organization that represents over 4,000 air conditioning contractors. ACCA supports the HVACR industry by bringing contractors together and providing technical, legal, and marketing resources. ACCA is “the only nationwide organization of, by and for the small businesses that design, install and maintain indoor environmental systems.”[7]

3.2.2 Manufacturers and Market Share

DOE examined its database of residential furnaces, manufacturers' websites, and product catalogs to identify residential furnace manufacturers. All manufacturers listed in DOE's database for residential furnaces are shown in Table 3.2.2. Manufacturers may offer multiple brand names. DOE identified more than 50 brands under which furnaces are manufactured and marketed.

Table 3.2.2: Manufacturers Whose Products are Included in DOE's Database*

Manufacturer	Parent Company (if applicable)	NWGF	WGF	MHGF	NWOF
Adams Manufacturing Company	N/A				X
Airwell-Fedders North America, Inc.	Elco Holdings Ltd.	X			
Airxcel Holdings, Inc.	Bruckmann, Rosser, Sherrill & Co. L.L.C.				
Bard Manufacturing Company	N/A		X		X
Boyertown Furnace Company	N/A				X
Carrier Corporation	United Technologies Corporation	X	X	X	X
Crown Boiler Company	Burnham Holdings, Inc.	X			X
ECR International	N/A	X			X
EFM Sales Company	General Machine Corporation				X
Goodman Manufacturing Company	Goodman Global Group, Inc.	X	X		
H.E.P. Materials Corp.	AllStyle Coil Company, L.P.				
Haier America	Haier Group Company	X			
Heat Controller, Inc.	N/A	X			
Kerr Energy Systems	Granby Industries Limited Partnership				X
Lennox Industries, Inc.	Lennox International, Inc.	X	X		X
National Comfort Products	N/A	X			
Newmac Manufacturing, Inc.	William Newport Holdings Limited				X
Nordyne, Inc.	Nortek, Inc.	X	X	X	X
Rheem Manufacturing Company	Paloma Group	X	X		X
Texas Furnace, LLC	AllStyle Coil Company, L.P.	X			
Thermo Products, LLC	Burnham Holdings, Inc.	X		X	X
Trane Inc.	Ingersoll Rand	X	X	X	X
York International Corporation	Johnson Controls, Inc.	X	X	X	X
Weil-McLain	SPX Corporation				
Whirlpool Home Cooling and Heating	Whirlpool Corporation	X	X		

Wolf Steel Ltd.	N/A	X			

* Airwell-Fedders North America, Inc., owned by Israeli parent company Elco Holdings Ltd., refers to Fedders, Eubank, and Airtemp products. Airxcel Holdings, Inc. is owned by private equity firm Bruckmann, Rosser, Sherrill & Co. L.L.C. and refers to subsidiaries Marvair and Suburban Manufacturing Company. Carrier Corporation is owned by United Technologies Corporation and refers to its subsidiaries: Carrier North America Home Comfort, Bryant Heating and Cooling Systems, International Comfort Products (ICP), Payne Heating and Cooling Systems, and Day & Night Heating and Cooling Products. Brands under ICP include: Heil, Tempstar, Arcoaire, Comfortmaker, Airquest, KeepRite, and Lincoln. ECR International includes Climate Energy, LLC and Oneida Royal. Goodman Manufacturing Company is a division of Goodman Global, Inc. and primarily markets its products under the Goodman and Amana brand names. Haier America is a subsidiary of the Haier Group Company. Heat Controller, Inc. manufactures and distributes the Comfort-Aire and Century brands. Lennox Industries, Inc., a subsidiary of Lennox International Inc., includes Lennox, Armstrong Air, AirEase, Concord, Ducane Air Conditioning and Heating, Allied Commercial, and Magic-Pak. Newmac Manufacturing, Inc. is a subsidiary of William Newport Holdings Limited. Nordyne, Inc. is a subsidiary of Nortek Incorporated and manufactures furnaces under the following brands: Broan, Elect-Aire, Frigidaire, Garrison, Gibson, Grandaire, Intertherm, Kelvinator, Maytag, Miller, Nutone, Philco, Tappan, Thermal Zone, and Westinghouse. Rheem Manufacturing Company refers to Rheem Manufacturing Company, Rheem Air Conditioning Division, Rheem Sales Company, Inc., and Ruud Air Conditioning Division. All Rheem and Ruud companies are subsidiaries of the Paloma Group. Sears, Roebuck and Company is a subsidiary of the Sears Holdings Corporation. Texas Furnace, LLC is a subsidiary of AllStyle Coil Company, L.P. Crown Boiler Company and Thermo-Products, LLC are owned by Burnham Holdings, Inc. Trane Inc. manufactures products under the American Standard and Trane brand names. Ingersoll Rand owns Trane. York International Corporation refers to the following brands: Coleman, Evcon, Fraser-Johnston, Guardian, Luxaire, and York. York International Corp. is owned by Johnson Controls. Weil-McLain, which includes Williamson-Thermoflo, is a division of SPX Corporation. Whirlpool Home Cooling and Heating is a division of the Whirlpool Corporation. Wolf Steel Ltd. also does business as Napoleon Fireplaces.

The domestic gas furnace market is almost entirely held by seven U.S. manufacturers: Carrier, Goodman, Lennox, Trane[f], Rheem, York, and Nordyne.[8] Figure 3.2.1 shows the 2008 market shares for residential furnace manufacturers as depicted in the September 2009 issue of *Appliance Magazine*.

[f] Prior to 2007, Trane was a subsidiary of American Standard Companies. On November 28, 2007 Trane separated from the two other branches of American Standard Companies. On June 5, 2008, Ingersoll Rand acquired Trane. For more information, visit www.trane.com/Corporate/About/history.asp.

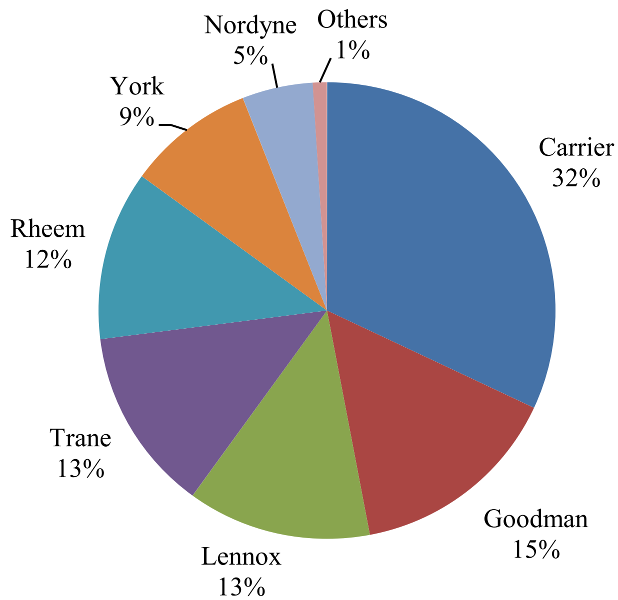

Figure 3.2.1 2008 Market Shares for U.S. Manufacturers of Residential Gas Furnaces[9]

Two of these major manufacturers, Nordyne and York, are also major players in the market for mobile home gas furnaces. Other manufacturers of mobile home gas furnaces include Trane, Carrier, and Thermo Pride.

In contrast to the gas furnace market, the U.S. residential oil-fired furnace market is composed almost entirely of small manufacturers. Small manufacturers include Adams, Bard, Boyertown, Crown Boiler, ECR International, EFM, Kerr, and Newmac; larger manufacturers include Thermo Pride and Lennox. Some of the large gas furnace manufacturers (including Carrier, Nordyne, Rheem, Trane, and York) also market oil-fired furnaces, although these furnaces are typically rebranded units from another original equipment manufacturer (OEM). DOE estimated the market shares of oil-fired furnace manufacturers based on publicly available information and manufacturer feedback. Manufacturers with an estimated market share of greater than or equal to 10 percent were designated as major players in the oil-fired furnace market, while manufacturers with an estimated market share of less than 10 percent were designated as minor players in the market. These manufacturers are shown in Table 3.2.3.

Table 3.2.3 Manufacturers of Residential Oil-Fired Furnaces

Major Manufacturers*	Minor Manufacturers*
Lennox	Adams
Thermo Pride	Bard
ECR International	Boyertown
	Crown Boiler
	EFM
	Kerr
	Newmac

*"Major manufacturers" are estimated to have at least 10 percent market share, while "minor manufacturers" are estimated to have less than 10 percent market share.

Many of the residential furnace manufacturers fabricate central air conditioners and heat pumps as well. DOE examined AHRI's Directory of Certified Product Performance for residential central air conditioners and heat pumps to identify residential central air conditioner and heat pump manufacturers. DOE identified 45 separate companies that manufacture and market air conditioner and heat pump systems and coils. The manufacturers found in the AHRI Directories of Certified Product Performance for residential central air conditioners and heat pumps are listed in Table 3.2.4, along with their parent company in parentheses, if applicable.

Table 3.2.4 Manufacturer Brand Names Found in the AHRI's Directories of Certified Product Performance for Residential Central Air Conditioners and Heat Pumps[10]

Aaon, Inc.	Lennox International	National Coil Company
Aire-Flo	Friedrich Air Conditioning Co. (US Natural Resources, Inc.)	National Comfort Products (National Refrigeration and Air Conditioning Products, Inc.)
Airquest	Fujitsu General America, Inc. (Fujitsu General Group)	Nutone
Airwell-Fedders North America, Inc.	GD Midea Commercial Air-Conditioning Equipment Co., Ltd.	Quietside
Bard Manufacturing Company	Goodman/Amana (Goodman Global, Inc.)	Rheem/Ruud (Paloma Global)
Beutler Corporation	Grandaire	Style Crest Products
Broan	Haier America (Haier Group)	Summit Manufacturing, Inc.
Century (Heat Controller)	Heat Controller, Inc.	Texas Furnace, LLC
Cold Point Corp.	Intertherm	Thermo Products, Inc. (Burnham Holdings, Inc.)
Dayton Electric Manufacturing Company (WW Grainger, Inc.)	Kenmore (Sears Holdings Corporation)	Trane/American Standard (Ingersoll Rand)
Eair LLC	LG Electronics, Inc.	Unitary Products Group (York/Johnson Controls)
Ecotemp	Mammoth, Inc. (Thomas H. Lee Partners, LP)	United Refrigeration Distributors, Inc.
Enviromaster International (ECR International, Inc.)	McQuay International (Daikin Industries, Ltd.)	V-Aire
Espitech, LLC	Mitsubishi Electric and Electronics USA, Inc.	Whirlpool
International Comfort Products - Carrier/UTC	Nordyne	Xenon

Figure 3.2.2 displays the 2007 market shares for the residential central air conditioner market. The seven largest residential gas furnace manufacturers also dominate the residential central air conditioner and heat pump industry. These seven manufacturers include Carrier,

Goodman, Trane[g], Lennox, Rheem, York, and Nordyne and control 97 percent of the central air conditioner and heat pump market, as of 2008.

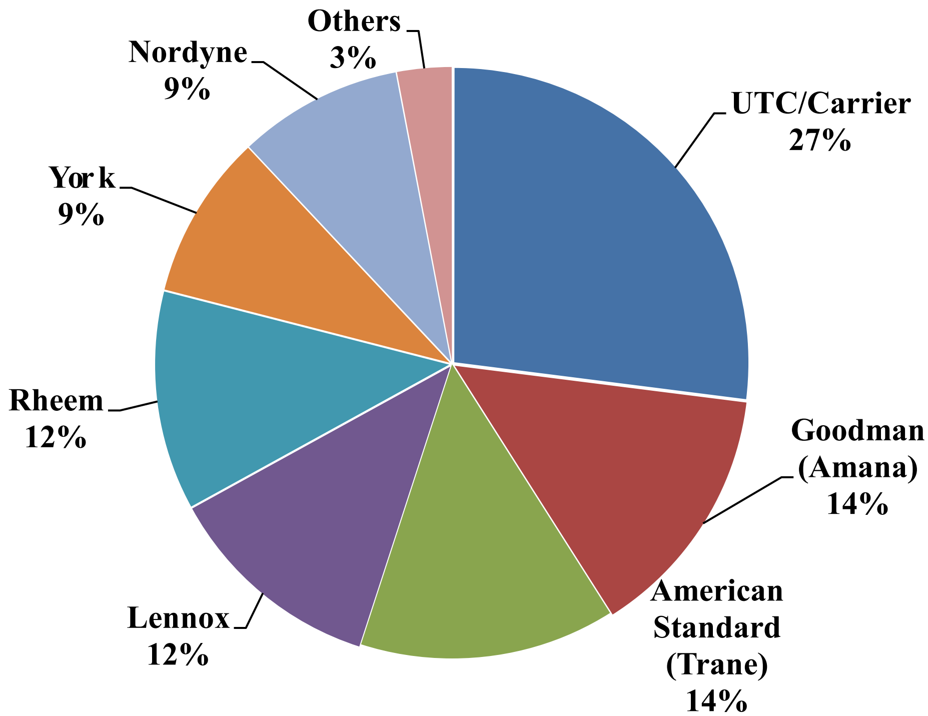

Figure 3.2.2 2008 Market Shares for Unitary Air Conditioners and Heat Pumps[11]

3.2.2.1 Mergers and Acquisitions

A trend in the both the residential furnace industry and the residential central air conditioning and heat pump industry over the past decades has been the consolidation of major manufacturers. In the last ten years or so, the seven major manufacturers (*i.e.*, Goodman, Lennox, Carrier, York, Rheem, Nordyne, and Trane) have gone through various mergers and acquisitions, and have materialized as differentiated leaders in the air conditioning and heat pump manufacturing industry. A brief summary of the recent history of each of the seven largest manufacturers is as follows:

- Goodman Global, Inc. was founded and purchased Janitrol in 1982. In 1997, Goodman acquired Amana, which was then sold to Maytag in 2001, and later to Whirlpool when Whirlpool acquired Maytag in 2006.
- Lennox Industries is a subsidiary of Lennox International, Inc., a holding company that was created in 1984. Lennox International acquired Armstrong Air Conditioning Inc. in 1988. In 1999, Lennox International completed an Initial Public Offering and

[g] Prior to 2007, Trane was a subsidiary of American Standard Companies. On November 28, 2007 Trane separated from the two other branches of American Standard Companies. On June 5, 2008, Ingersoll Rand acquired Trane. For more information, visit www.trane.com/Corporate/About/history.asp.

became a public company[12]. Around this time, Lennox also acquired Service Experts and other equipment service companies.

- Carrier has been a wholly-owned subsidiary of United Technologies Corporation since 1979. In 1999, Carrier Corporation acquired International Comfort Products (ICP). [13]
- York Unitary Products Group and York International are subsidiaries of Johnson Controls, Inc. Johnson Controls, Inc. purchased York in 2005. [14]
- Rheem is a privately held firm that was acquired by Paloma Industries of Japan in 1987. Paloma Industries also acquired Rheem Australia (Solahart) in 2002. [15]
- Nordyne is a subsidiary of the privately held Nortek, Inc. [16]
- Trane Inc. was acquired by American Standard Companies in 1984. In 2007 Trane separated from American Standard and was subsequently bought by Ingersoll-Rand in 2008.

3.2.2.2 Small Businesses

DOE considers the possibility of small businesses being particularly impacted by the promulgation of minimum energy conservation standards for residential central air conditioners and heat pumps. The Small Business Administration (SBA) defines small business manufacturing enterprises for residential central air conditioners and heat pumps as having 750 employees or fewer.[17] SBA lists small business size standards that are matched to industries as they are described in the North American Industry Classification System (NAICS). A size standard is the largest that a for-profit concern can be and still qualify as a small business for Federal Government programs. These size standards are generally the average annual receipts or the average employment of a firm. For both residential furnaces and residential central air conditioners and heat pumps, the size standard is matched to NAICS code 333415, Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing, which has a size standard of 750 employees.

DOE further studied the potential impacts on these small businesses in detail and presented the results in manufacturer impact analysis (MIA) (Chapter 12 of this TSD). DOE has identified the following as either small business furnace manufacturers or small business residential central air conditioner and heat pump manufacturers with the small business parent companies in parentheses if applicable:

- Adams Manufacturing Company
- Aerosys
- Bard Manufacturing Company
- Boyertown Furnace Company
- Eair, LLC
- ECR International
- EFM
- Espitech, LLC
- H.E.P. Materials Corp. (AllStyle Coil Company)
- Heat Controller, Inc.
- National Coil Company

- National Comfort Products
- Newmac Manufacturing, Inc. (William Newport Holdings Limited)
- Texas Furnace, LLC (AllStyle Coil Company)

3.2.3 Distribution Channels

A single distribution channel represents the vast majority of the HVAC market. Simply, the OEM assembles the system and sells it to a distributor; the distributor warehouses and sells the unit to a contractor (also known as a dealer); and the contractor sells the unit to the final consumer and performs the installation. Some manufacturers use a “direct-to-dealer” model in which the manufacturer sells to a contractor and the contractor sells the unit to the final consumer. The final consumer varies in the replacement and in the new construction market. In the replacement market, the final consumer is usually the homeowner, as illustrated in Figure 3.2.2 and Figure 3.2.3, and is very influential in product selection. Replacements "in kind" (replacing a unit with a similar or identical product) are common, although premium products are also commonly sold in this market. Replacements represent approximately 75 percent of non-weatherized gas furnace sales, 50 percent of mobile home gas furnace sales, and 90 percent of oil furnace sales in the United States.[18] In the new construction market, a builder or general contractor is effectively the final end-user, as shown in Figure 3.2.4. In the new construction market, the home builder has a much stronger influence than the homeowner, who typically has little choice in what kind of system is installed. The new construction market tends to be a low-cost, low-efficiency market, as the decision-makers are not the beneficiary of the system installed. After installation, mechanical contractors typically perform additional lifecycle service on the system, including inspection, maintenance, and repair.

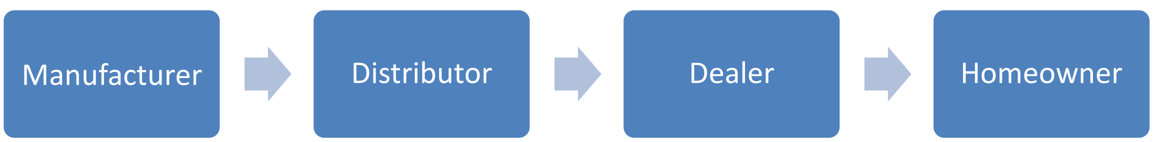

Figure 3.2.3 Traditional Distribution Chain in Replacement Market

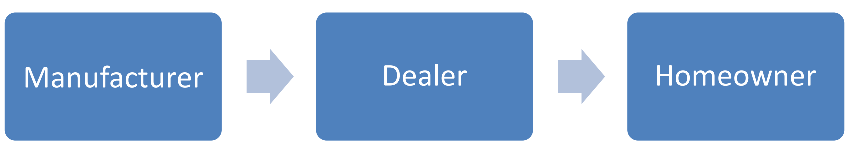

Figure 3.2.4 Direct-to-Dealer Distribution Chain in Replacement Market

Figure 3.2.5 Distribution Chain in New Construction Market

3.2.4 Regulatory Programs

The following section details current regulatory programs mandating energy conservation standards for residential furnaces and residential central air conditioners and heat pumps. Section 3.2.3.1 discusses current Federal energy conservation standards. Sections 3.2.3.2 and 3.2.3.3 review standards in both Canada and Mexico that may impact the companies servicing the North American market.

3.2.4.1 Current Federal Energy Conservation Standards

Part A of Title III of EPCA addresses the energy conservation standards for consumer products other than automobiles, which include residential furnaces and residential central air conditioners and heat pumps. (42 U.S.C. 6291-6309) The current Federal standards prescribed by EPCA have applied since January 1, 1990, for mobile home furnaces and January 1, 1992, for all other furnaces except "small" furnaces. (42 U.S.C. 6295(f)(1)–(2)) Table 3.2.5 presents the current Federal energy conservation standards for residential furnaces as prescribed by section 325(f) of EPCA.

Table 3.2.5 Current Federal Energy Conservation Standards Established by EPCA, as Amended by NAECA

Product Class	Minimum AFUE %
Furnaces (excluding classes noted below)	78
Mobile home furnaces	75
Small furnaces (having an input rate of less than 45,000 Btu/h)	78

Pursuant to 42 U.S.C. 6295(f)(4)(B), DOE amended the energy conservation standards for residential furnaces in a final rule issued on November 19, 2007 (hereafter referred to as the November 2007 Rule). 72 FR 65135. These standards, shown in Table 3.2.6, have a compliance date of November 19, 2015, prior to the compliance date of this rulemaking (unless DOE adopts the levels and compliance dates in the consensus agreement). Because they will be the minimum energy efficiency standards at the time of this rulemaking's compliance date, DOE has adopted them as the baseline efficiency levels for its analyses, as discussed in the final rule.

Table 3.2.6 Federal Energy Conservation Standards Established by the November 2007 Rule

Product Class	Minimum AFUE %
Non-weatherized gas furnaces	80
Weatherized gas furnaces	81
Mobile home gas furnaces	80
Non-weatherized oil-fired furnaces	82

The most recent Federal standards for residential central air conditioners and heat pumps went into effect on January 23, 2006, and are codified in 10 CFR Part 430.32. Table 3.2.7 presents the current Federal energy conservation standards for residential central air conditioners and heat pumps as presented in part (c)(2) of 10 CFR Part 430.32.

Table 3.2.7 Current Federal Energy Conservation Standards for Residential Central Air Conditioners and Heat Pumps[h]

Product class	SEER*	HSPF**
(i) Split system air conditioners	13.0	-
(ii) Split system heat pumps	13.0	7.7
(iii) Single package air conditioners	13.0	-
(iv) Single package heat pumps	13.0	7.7
(v)(A) Through-the-wall air conditioners and heat pumps-split system†	10.9	7.1
(v)(B) Through-the-wall air conditioners and heat pumps-single package†	10.6	7.0
(vi) Small duct, high velocity systems	13.0	7.7
(vii)(A) Space constrained products-air conditioners	12.0	-
(vii)(B) Space constrained products-heat pumps	12.0	7.4

* SEER is seasonal energy efficiency ratio.
** HSPF is heating seasonal performance factor.
† As defined in 10 CFR Part 430.2, this product class applies to products manufactured before January 23, 2010.

3.2.4.2 Canadian Energy Conservation Standards

The Natural Resources Canada (NRCan) Office of Energy Efficiency regulation mandates minimum energy conservation standards for residential furnaces and residential central air conditioners and heat pumps that apply to imports and interprovincial trade. The standards for furnaces are expressed as minimum annual fuel utilization energies (AFUEs), rated according to the Canadian test standard CAN/CSA P.2-2007 entitled *Testing method for measuring annual fuel utilization efficiency of residential gas-fired furnaces and boilers;* (*CSA P.2*). These standards apply to automatic operating gas-fired central forced-air furnaces that use propane or natural gas and have an input rate not exceeding 225,000 Btu/h, but do not apply to furnaces for mobile homes or recreational vehicles. The furnace standards and their compliance dates are shown in Table 3.2.9, while the air conditioner and heat pump standards are contained in Table 3.2.9 and became effective in November 2006.

[h] Current Federal energy conservation standards for residential central air conditioners taken from 10 CFR 430.32(c)(2).

Table 3.2.8 Canadian Energy Conservation Standards for Residential Gas Furnaces[19]

Product	Minimum AFUE Standard %	Compliance Date
Gas furnaces, other than those with an integrated cooling component that are outdoor or through-the-wall* gas furnace, that have an input rate no greater than 225,000 Btu/h and that use single-phase electric current	90	On or after December 31, 2009
Gas furnaces that are outdoor furnaces with an integrated cooling component, that have an input rate no greater than 225,000 Btu/h and that use single-phase electric current	78	On or after December 31, 2009
Gas furnaces that are through-the-wall with an integrated cooling component, that have an input rate no greater than 225,000 Btu/h and that use single-phase electric current	78	On or after December 31, 2009 until December 30, 2012
Gas furnaces that are through-the-wall with an integrated cooling component, that have an input rate no greater than 225,000 Btu/h and that use single-phase electric current	90	On or after December 31, 2012

*With respect to gas furnaces, "through-the-wall" refers to gas furnaces that are designed and marketed to be installed in an opening in an exterior wall that is fitted with a weatherized sleeve.

Table 3.2.9 Canadian Energy Conservation Standards for Residential Central Air Conditioners and Heat Pumps[20]

Product	Minimum Energy Performance Standard
Air Conditioners – single package & split-system – cooling	SEER = 13
Heat Pumps – single package & split–system – cooling	SEER = 13
Heat Pumps – single package & split system – heating	HSPF V* = 6.7
AC & HP – through–the–wall, cooling – (until January 22, 2010)	SEER = 10.9
AC & HP – through–the–wall, cooling – (after January 23, 2010)	SEER = 12
Heat pumps – through–the–wall – heating – (until January 22, 2010)	HSPF V = 6.2
Heat Pumps – through–the–wall – heating – (after January 23, 2010)	HSPF V = 6.4
AC & HP – space–constrained – cooling	SEER = 12
Heat pumps – space–constrained – heating	HSPF V = 6.4
AC & HP – small duct, high velocity (SDHV) – cooling	SEER = 11
Heat Pumps – small duct, high velocity (SDHV) – heating	HSPF V = 5.9

* HSPF V is the Heating Seasonal Performance Factor – Region V. U.S. energy conservation standards specify HSPF as HSPF IV (*i.e.* HSPF – Region IV). HSPF V = HSPF IV/1.15.

3.2.4.3 Mexican Energy Conservation Standards

The National Commission for Energy Saving (CONAE)[i] is the agency responsible for developing, updating, and implementing Mexican official standards of energy efficiency. CONAE published NOM-011-ENER-2006 (which updated previous standard effective in 2002) in June 2007. The standards prescribe minimum efficiencies for central, package, and split system central air conditioners with cooling capacities between 30,000 and 65,000 Btu/h[j] at a minimum of 13 SEER.[k]

Table 3.2.5 Mexican Energy Conservation Standards for Residential Central Air Conditioners[21]

Product	Minimum Energy Performance Standard
Air Conditioners – single package & split-system – cooling	SEER = 13

3.2.5 Non-Regulatory Programs

DOE identified several non-regulatory programs aimed at improving the energy efficiency of residential furnaces, central air conditioners and heat pumps. Two such programs are based on voluntary efficiency targets for residential central air conditioners and air-source heat pumps: the ENERGY STAR program and the Consortium for Energy Efficiency (CEE) initiative. In addition, DOE identified rebate programs and Federal and State tax credits for residential purchasers of higher-efficiency central air conditioners and heat pumps, and reviewed Federal procurement specifications for these products as well.

3.2.5.1 ENERGY STAR

ENERGY STAR[l] is a voluntary labeling program conducted by the U.S. Environmental Protection Agency (EPA) and DOE that identifies and promotes energy-efficient products. To qualify, a product must usually exceed federal minimum standards by a specified amount, or if no federal standard exists, it must meet minimum efficiency levels set by the program and/or exhibit selected energy saving features. ENERGY STAR creates minimum energy efficiency specifications for various products, including split system and single package air conditioners and heat pumps. ENERGY STAR originally set specifications for central air conditioners and heat pumps in 1995, followed by revisions in 2002, 2006, and 2009. The current (2009) ENERGY STAR levels are shown in Table 3.2.10.

[i] For more information visit www.conae.gob.mx/wb/CONAE/english/_rid/6600?page=1.
[j] Cooling capacity is specified in the standard as 8,800W to 19,050W.
[k] Mexican efficiency standards for central air conditioners are specified in terms of *Relación de eficiencia energética estacional* (REEE). NOM-011-ENER-2006 mandates a minimum efficiency of 3.81 REEE, which is equivalent to 13 SEER.
[l] For more information, visit www.energystar.gov.

Table 3.2.10 ENERGY STAR Levels for Split System and Single Package Residential Central Air Conditioners and Heat Pumps [22]

Product Class	SEER Rating	EER Rating*	HSPF Rating
Split system air conditioners	14.5	12.0	-
Split system heat pumps	14.5	12.0	8.2
Single package air conditioners	14.0	11.0	-
Single package heat pumps	14.0	11.0	8.0

* EER is energy efficiency ratio.

3.2.5.2 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a coalition of energy efficiency programs in the U.S. and Canada, including state energy efficiency offices, energy efficiency advocacy groups, and utilities, engaged in establishing common goals and methods for promoting energy efficiency across a broad range of products. The CEE Residential Central Air Conditioner and Heat Pump Initiative promotes the use of high-efficiency residential central air conditioners and heat pumps, along with proper installation and sizing of these products. CEE identifies three tiers of efficiency for split system central air conditioners and two tiers of efficiency for split system heat pumps and single package central air conditioners and heat pumps. For split system central air conditioners and package central air conditioners and heat pumps, the CEE Tier 1 levels are the same as the ENERGY STAR levels. The CEE tier requirements are shown in Table 3.2.11.

Table 3.2.11 CEE Tiers for Residential Central Air Conditioners and Heat Pumps[23]

Product Class	CEE Tier	SEER Requirement	EER Requirement	HSPF Requirement
Split System Central Air Conditioners	Tier 1	14.5	12.0	-
	Tier 2	15.0	12.5	-
	Tier 3	16.0 or higher	13.0 or higher	-
Single Package Central Air Conditioners	Tier 1	14.0	11.0	-
	Tier 2	14.0 or higher	12.0 or higher	-
Split System Heat Pumps	Tier 1	14.5	12.0	8.5
	Tier 2	15.0 or higher	12.5 or higher	8.5 or higher
Single Package Heat Pumps	Tier 1	14.0	11.0	8.0
	Tier 2	14.0 or higher	12.0 or higher	8.0 or higher

3.2.5.3 Consumer Rebate Programs

In addition to the Federal and State tax credits available for purchasers of residential furnaces, many States and local utility companies offer rebates for higher efficiency furnaces, typically for existing home retrofits only. DOE maintains a database of such rebates, called the Database of State Incentives for Renewables & Efficiency (DSIRE), in addition to information on other state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. For more information on individual rebate programs, please visit the DSIRE website at www.dsireusa.org.

3.2.5.4 Federal Tax Credits

Until December 31, 2010, a Federal tax credit provides consumers a credit toward their

Federal income tax if they purchase qualifying residential furnaces, central air conditioners or heat pumps. This tax credit applies only to products being installed in existing homes, not to furnaces, central air conditioners and heat pumps for new housing construction. This Federal tax credit is 30 percent of the installation cost (equipment and labor) to the consumer of the new system, with a maximum limit of $1,500. To qualify for the Federal tax credit, products must meet varying levels of efficiency depending on the product class. Table 3.2.12 and Table 3.2.13 describe the required efficiency level for each product class, along with the amount of the Federal tax credit available.

Table 3.2.12 Federal Tax Credits for Residential Furnaces[24]

Product	Requirement	Available Tax Credit
Natural gas or propane furnace	≥ 95% AFUE	30% of cost, up to $1,500
Oil-fired furnace	≥ 90% AFUE	30% of cost, up to $1,500
Advanced main air circulating fan	< 2% of the furnace's total energy	30% of cost, up to $1,500

Table 3.2.13 Federal Tax Credits for Residential Central Air Conditioners and Heat Pumps[25]

Product	EER Requirement	SEER Requirement	HSPF Requirement	Available Tax Credit
Central Air Conditioner – Split Systems	≥ 13.0	≥16.0	N/A	30% of cost, up to $1,500
Central Air Conditioner – Single Package	≥12.0	≥ 14.0	N/A	30% of cost, up to $1,500
Air Source Heat Pump – Split Systems	≥ 12.5	≥15.0	≥ 8.5	30% of cost, up to $1,500
Air Source Heat Pump – Single Package	≥ 12.0	≥14.0	≥8.0	30% of cost, up to $1,500

3.2.5.5 State Tax Credits

DOE also identified four states that have tax credits for residential furnaces: Montana, Orgeon, Indiana, and Kentucky. These same four states were also identified as having tax credits for central air conditioners and heat pumps.

Montana has had an Energy Conservation Tax Credit for residential energy conservation measures since 1998.[26,27] The tax credit covers a variety of residential energy and water efficiency installations, including ENERGY STAR heating and cooling equipment. The amount of the credit increased in 2002 from 5 percent of equipment costs (up to $150) to 25 percent (up to $500 per taxpayer). The Energy Conservation Tax Credit can be used for equipment installed in new construction or remodeling projects, with the tax credit allowed only for the portion of the cost and materials above "established standards of construction."

Table 3.2.14 State Tax Credits for Residential Gas Furnaces[28]

State	AFUE Requirement %	Other Requirements	Available Tax Credit
Oregon	92	Electrically-efficient fan motor, direct vent	$350
Montana	Higher than the previous system, or exceeding 90*	N/A	25% of cost, up to $500
Indiana	90	N/A	20% of cost or $100, whichever is less
Michigan	90	Annual income of ≤$37,500 for single filers and ≤$75,000 for married couples filing jointly	10% of cost, up to $75 for single filers and $150 for joint filers

*Tax credit is available in new construction for investments that meet or exceed ENERGY STAR levels at 90% AFUE. In tax year 2009 exclusively, tax credit was available for replacements of an existing heating system with a new one of the same style or type that has a higher efficiency rating, whether or not the new heating system meets or exceeds the established standards for new construction or with a new system that is of a different style or type that exceeds the requirements for new construction.

Oregon's Residential Energy Tax Credit (RETC) was created in 1977 to encourage the use of renewable resources in households. The Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers; participation in the program increased significantly after they became eligible. The program subsequently added credits for high-efficiency heat pump systems, air conditioners, and water heaters (2001). furnaces and boilers (2002), and other equipment and measures.[29]

To qualify, a central air conditioning or heat pump system must have a performance verification test by a tax credit-certified technician. For this verification test there is a separate tax credit of 25% of the cost of the test and any needed repairs, up to $250. Purchasers of high-efficiency central air conditioners or heat pumps who have premium efficiency ducts qualify for an additional $150 tax credit.[29]

Central air conditioning split-system units must have EER of 13.0 or higher. The tax credit for qualifying central air conditioning systems is the amount listed in Table 3.2.8 or 25 percent of the net purchase price, whichever is less.

Table 3.2.15 Oregon Tax Credit for Central Air Conditioners[30]

Tier	Minimum Efficiency EER	Maximum Tax Credit Amount
RAC4	13.0	$160
RAC5	14.0	$225
RAC6	15.0	$300

Air-source heat pump split-system equipment must have HSPF of 9.0 or higher and EER of 12 or higher. Table 3.2.9 shows the heat pump tax credit levels by system efficiencies.

Table 3.2.16 Oregon Tax Credits for Heat Pumps

HSPF	Tax Credit Amount		
	At 12 EER	At 12.5 EER	At 13 EER
9.0	$300	$320	$340
9.5	$300	$360	$380
10.0	$300	$360	$430

Indiana offers a tax credit beginning in 2009 to individuals and small businesses for the costs associated with purchasing ENERGY STAR-qualified central air conditioners and other appliances. The credit may be claimed against the state income tax, insurance premium tax, or financial institutions tax. The amount of the tax credit is set at 20% of the expenditures for qualified heating and cooling equipment up to $100 per taxable year. The credit is for expenditures in 2009 and 2010 and there is no carryover.[31,32]

Kentucky offers a 30 percent state income tax credit beginning in 2009 for taxpayers who install certain energy efficiency measures on their principal residence or residential rental property. These energy efficiency measures include "Qualified Energy Property Installation," which includes heat pumps and central air conditioners, among others. Equipment must meet the efficiency guidelines specified in the Federal tax credit for residential energy property (see Table 3.2.7). The total annual tax credit for this equipment may not exceed $250. These credits apply to equipment purchased in taxable years 2009 to 2015 and may be carried forward for one year.[33],[34]

3.2.5.6 FEMP Procurement Guidelines

DOE reviewed the Federal Energy Management Program (FEMP) procurement guidelines for Federal government equipment purchasing. The mission of DOE's FEMP [m] is "to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites."[35] FEMP helps Federal buyers identify and purchase energy-efficient equipment.

FEMP designates standards for residential gas furnaces, central air conditioners and heat pumps purchased by the Federal government. The designated FEMP gas furnace standard level is

[m] For more information, please visit www.eere.energy.gov/femp.

the ENERGY STAR level, or 90% AFUE.[36] Table 3.2.10 shows the FEMP performance requirements for residential central air conditioners and Table 3.2.11 shows the requirements for air source heat pumps.[37,38]

Table 3.2.17 FEMP Performance Requirements for Residential Central Air Conditioners

System Type	SEER	EER
Split	14.5 or greater	12.0 or greater
Single package	14.0 or greater	11.0 or greater

Table 3.2.18 FEMP Performance Requirements for Air Source Heat Pumps

System Type	HSPF	EER	SEER
Split	8.0 or greater	11.0 or greater	13.0 or greater
Single package	7.6 or greater	10.5 or greater	12.0 or greater

3.2.6 Industry Cost Structure

DOE developed an industry cost structure for residential central air conditioners and heat pumps from publicly available information from the Census Bureau's ASM and the SEC 10-K[n] reports filed by publicly owned manufacturers. Companies subject to SEC regulations must report sales, costs of goods sold, gross profits, and various overhead costs, in addition to overall performance and operations for the year. DOE analyzed SEC 10-K reports from 2004 to 2008 and developed a representative cost structure for the furnace industry. The cost of materials as a percentage of revenue for each product can fluctuate as raw material costs change from year to year. For more information on the furnace and central air conditioner industry cost structure derived using SEC 10-K data, see chapter 12 of this TSD.

The Census Bureau collects industry-wide employment data based on NAICS codes. As stated previously, manufacturers of residential central air conditioners and heat pumps are grouped into the Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing category, which is NAICS code 333415. Table 3.2.19 presents the residential air conditioning and warm air heating equipment manufacturing employment levels and earnings from 1997 to 2008 according to the NAICS.

[n] For more information, please visit www.sec.gov.

Table 3.2.19 Air Conditioning and Warm Air Heating Equipment Industry Employment and Payroll Data [39,40,41]

Year	Production Workers	Total Number of Employees	Payroll for All Employees *$, thousands*
2008	70,772	96,502	4,010,045
2007	74,728	101,485	4,034,043
2006	74,909	98,097	4,019,813
2005	76,011	102,354	3,942,808
2004	73,106	99,035	3,691,029
2003	77,488	104,668	3,776,417
2002	80,417	108,274	3,815,747
2001	88,978	118,876	3,950,483
2000	97,978	127,384	4,267,872
1999	95,904	123,962	4,043,064
1998	91,994	120,011	3,844,667
1997	90,968	119,386	3,678,996

The statistics illustrate a steady decline in both the number of production and non-production workers in the industry after the year 2000, with the only exception being in 2005, when the number of employees increased. The overall decline in employment may be a result of industry consolidation, increased automation in production, or manufacturers moving their facilities outside of the United States to reduce labor costs. The increase in employment in 2005 may have resulted from manufacturers of residential central air conditioners in heat pumps augmenting the number of production workers to deal with the increased demand for central air conditioners and heat pumps that occurred prior to the most recent Federal standards becoming effective in 2006 (as shown by the sharp increase in residential central air conditioner and heat pump shipments in 2005).

Table 3.2.20 presents the costs of materials and industry payroll as a percentage of value of shipments from 1997 to 2006.

Table 3.2.20 Air Conditioning and Warm Air Heating Equipment Industry Cost Data [10,11]

	Percent of Value of Shipments		
Year	**Cost of Materials**	**Cost of Payroll for Production Workers**	**Cost of Total Payroll**
2006	53.2	8.9	13.8
2005	53.8	8.5	13.8
2004	51.1	8.8	14.2
2003	50.6	9.5	15.4
2002	49.4	9.8	15.9
2001	52.6	9.8	15.8
2000	53.0	10.1	16.0
1999	53.4	9.8	15.4
1998	54.9	9.9	15.4
1997	54.2	10.1	16.0

The cost of materials as a percentage of value of shipments has fluctuated slightly over the 10-year period. The cost of payroll for production workers as a percentage of value of shipments has followed a declining pattern since 1998, with the exception of only the year 2006, during which the cost of payroll increased from the previous year. Finally, the cost of total payroll as a percentage of value of shipments has generally declined since 2000, illustrating a reduction in industry non-production or administrative employees, possibly the product of selling, general, and administrative (SG&A) cost-cutting measures.

A detailed financial analysis of the manufacturers of each of the product types covered by this rulemaking is presented in the manufacturer impact analysis (MIA) (Chapter 12 of this TSD). This analysis identifies key financial inputs including cost of capital, working capital, depreciation, capital expenditures, etc.

3.2.7 Product Lifetime

The lifetime of residential furnaces, central air conditioners and heat pumps can vary greatly depending on how often the system is used (which is dependent upon the climate of the region where the product is installed and the personal preferences of the consumer) and how regularly it is maintained and serviced. DOE reviewed available literature to determine the appropriate lifetime for residential central air conditioners and heat pumps. Generally, most sources estimate the lifetime of residential furnaces, central air conditioners and heat pumps to be in the range of 10 to 20 years. *Appliance Magazine* publishes an Annual Portrait of the U.S. Appliance Industry in which it estimates low, high, and average lifetimes for a range of home appliances, including gas and oil-fired furnaces, unitary air conditioners and heat pumps, based on input from appliance experts and many additional sources. *Appliance Magazine* estimates the typical service lifetime range of a gas furnace is 12 to 17 years, while the typical service lifetime range of an oil-fired furnace is 15 to 19 years. It also estimates the average lifetime of a gas furnace as 15 years and the average lifetime of an oil-fired furnace as 17 years. [42] Similarly, *Appliance Magazine* estimates the average lifetime of a residential central air conditioner as 11 years and the average lifetime of a residential air-source heat pump as 12 years. AHRI estimates the average lifetime of a central air conditioner as 12 to 15 years and the average lifetime of a heat pump as 14 years.[43]

DOE's methodology for determining the lifetime of the products under analysis is described in detail in chapter 8 of this TSD. Using a combination of RECS data, large-scale surveys of commercially available products, and manufacturer information about historical shipments and stock, DOE estimated that the median lifetimes of non-weatherized gas furnaces, mobile home gas furnaces, and non-weatherized oil-fired furnaces are 20.4 years, 16.9 years, and 26.3 years, respectively. DOE used national survey data along with manufacturer shipment data to calculate the distribution of air conditioner and heat pump lifetimes. The mean central air conditioner and heat pump lifetimes from the distributions were determined to be 19.0 and 16.2 years, respectively. Additional information about product lifetimes is contained in chapter 8 (life-cycle cost and payback period analysis) of this TSD.

3.2.8 Market Performance Data

DOE examined the AHRI,[44] the CEC,[45] and ENERGY STAR[46] directories and other publicly available data from manufacturers' catalogs of residential furnaces to develop an understanding of the industry and its market. These databases contain information such as manufacturer name, model number, input capacity, and efficiency. DOE only examined products that meet EPCA's definition of a residential furnace (see section 3.1.1 of this chapter). In addition, DOE excluded from its analysis any products that were manufactured for Canada or export only and any products in the AHRI Directory of Certified Product Performance that were not labeled as "active," meaning that they are currently being manufactured. For residential central air conditioners and heat pumps, DOE examined the AHRI Directory of Certified Product Performance to determine the characteristics of residential central air conditioners and heat pumps currently available on the market. By definition, residential central air conditioners and heat pumps are products with a cooling capacity below 65,000 Btu/h and are air-cooled;therefore, DOE did not examine any products that did not meet these criteria. Table 3.2.21 and Table 3.2.22 show the number of the models in the AHRI Directory of Certified Product Performance for each equipment class. As Table 3.2.22 indicates, the large majority of residential furnaces are non-weatherized gas furnaces, and there are comparatively few weatherized gas, mobile home gas, or oil-fired models. Manufacturers offer very few weatherized oil-fired and mobile home oil-fired furnace models. For air conditioners and heat pumps, Table 3.2.22 shows that the large majority of these products are split systems, and there are relatively few small-duct, high-velocity (SDHV) or space constrained (*i.e.,* through-the-wall) models.

Table 3.2.21 Number of Furnace Models Listed in the AHRI Directory of Certified Product Performance by Product Class

Product Class	Number of Models, as of June 7, 2010
Non-weatherized gas furnaces	5,257
Weatherized gas furnaces	1,847
Mobile home gas furnaces	157
Non-weatherized oil-fired furnaces	1,171
Weatherized oil-fired furnaces	12
Mobile home oil-fired furnaces	18

Table 3.2.22 Number of Central Air Conditioner and Heat Pump Models Listed in the AHRI Directory of Certified Product Performance by Product Class

Product Class	Number of Models, as of June 8, 2010
Split system air conditioners	250,966
Split system heat pumps	158,506
Single package air conditioners	2,290
Single package heat pumps	1.436
Small-duct, high-velocity system	732
Space constrained – air conditioners	12
Space constrained – heat pumps	2

3.2.8.1 Efficiency Data

DOE characterized the distribution of furnace efficiencies currently available to consumers by dividing the products listed in the DOE database into bins based on their efficiency and counting the number of models in each efficiency bin. The efficiency ratings were separated into bins in sizes of 1.0 percent or 0.5 percent AFUE, depending on the range of efficiencies within each product class. Each bin is named by its upper bound, and each bin's range includes its upper bound but does not include its lower bound (*e.g.*, the 80 percent AFUE bin includes all values 79.6 percent AFUE through 80.0 percent AFUE). Figure 3.2.6 though Figure 3.2.9 show histograms of the efficiency data for each product class.

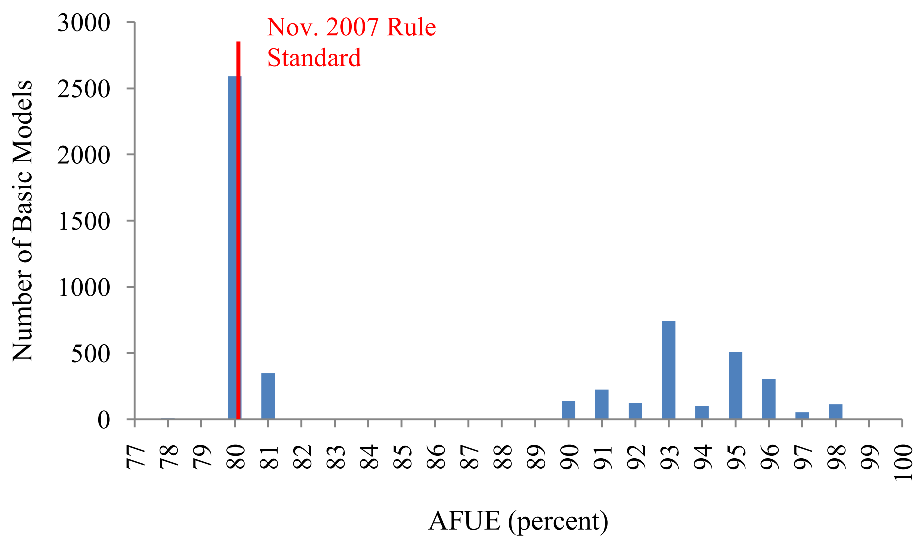

Figure 3.2.6 Distribution of Non-Weatherized Gas Furnace Models by AFUE

As Figure 3.2.6 shows, non-weatherized gas furnace efficiencies typically fall into two ranges: non-condensing (between 78 percent and 81 percent AFUE) and condensing (at or above 90 percent AFUE). The vast majority of non-condensing models are at 80 percent AFUE, while the largest number of condensing models is at 93 percent AFUE.

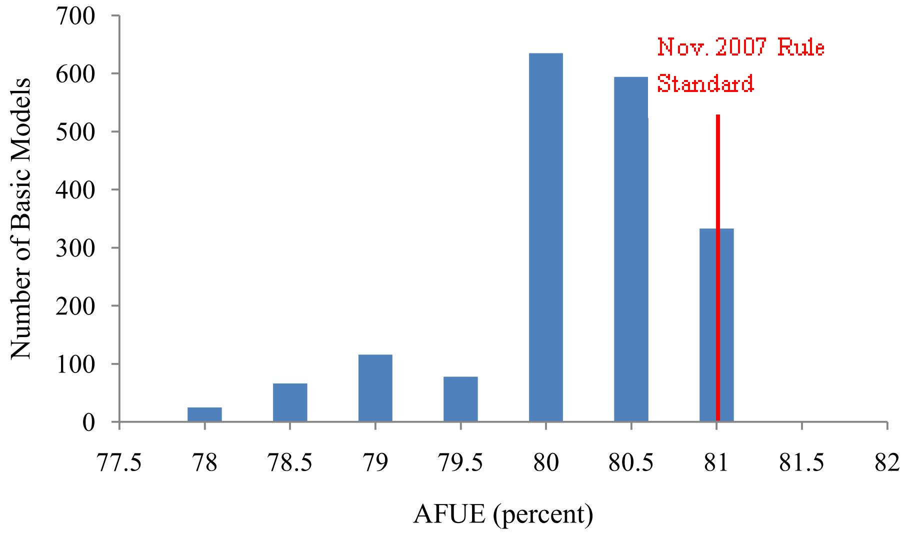

Figure 3.2.7 Distribution of Weatherized Gas Furnace Models by AFUE

Figure 3.2.7 shows that weatherized gas furnaces have efficiencies ranging from 78 percent AFUE up to 81 percent AFUE. The highest concentration of models is at 80 percent AFUE.

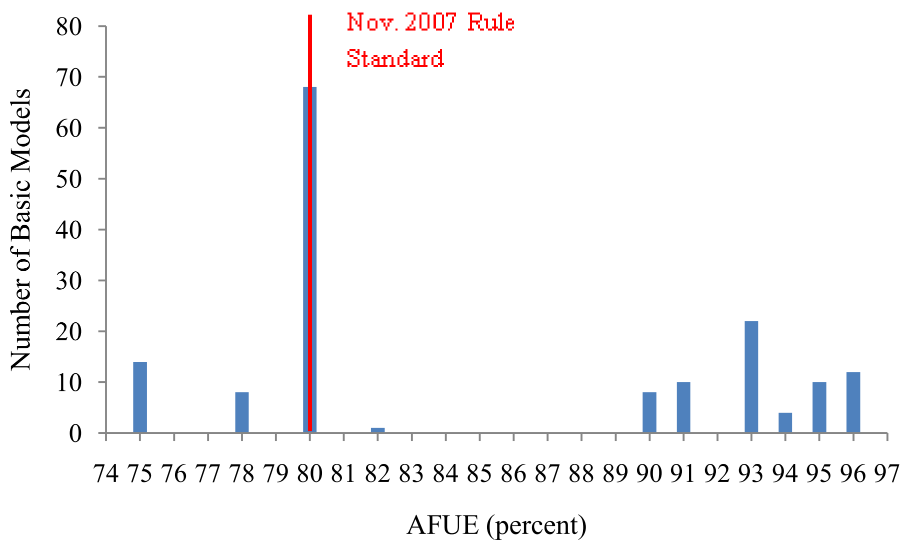

Figure 3.2.8 Distribution of Mobile Home Gas Furnace Models by AFUE

As shown in Figure 3.2.8, the distribution of mobile home gas furnaces is similar to that of non-weatherized gas furnaces in that the majority of models fall into one of two ranges – non-condensing (*i.e.*, 78 to 82 percent AFUE) or condensing (*i.e.*, at or above 90 percent AFUE). As with non-weatherized gas furnaces, most non-condensing mobile home gas furnaces are concentrated at 80 percent AFUE; and most condensing mobile home gas furnaces are at 93 percent AFUE.

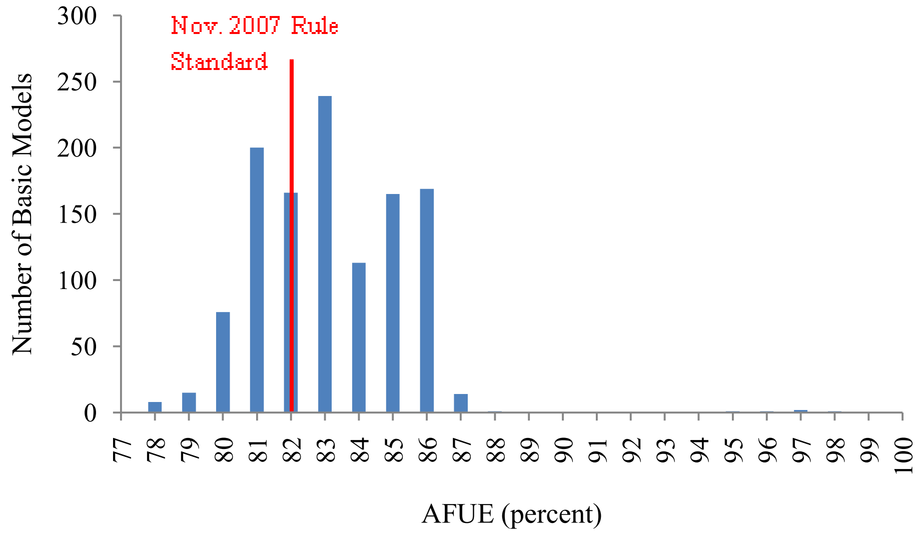

Figure 3.2.9 Distribution of Non-Weatherized Oil-Fired Furnace Models by AFUE

The oil-fired furnace market, illustrated in Figure 3.2.9, is primarily non-condensing, while only a few models manufactured in the condensing range (which, for oil-fired furnaces, occurs at approximately 88 percent AFUE). The market is concentrated around 83 percent AFUE. Very few models are available between 95 and 98 percent AFUE.

DOE conducted a similar analysis of the efficiency of residential central air conditioners and heat pumps currently available on the market in AHRI's Certified Product Performance Directory. DOE divided the products into bins based on their efficiency and counted the number of models in each efficiency bin. The efficiency ratings were separated into efficiency bins of one SEER each, and the SEER ratings are calculated to two decimal points. Figure 3.2.10 through Figure 3.2.14 show histograms of the efficiency data for split system and single package central air conditioners and heat pumps, as well as for SDHV systems.

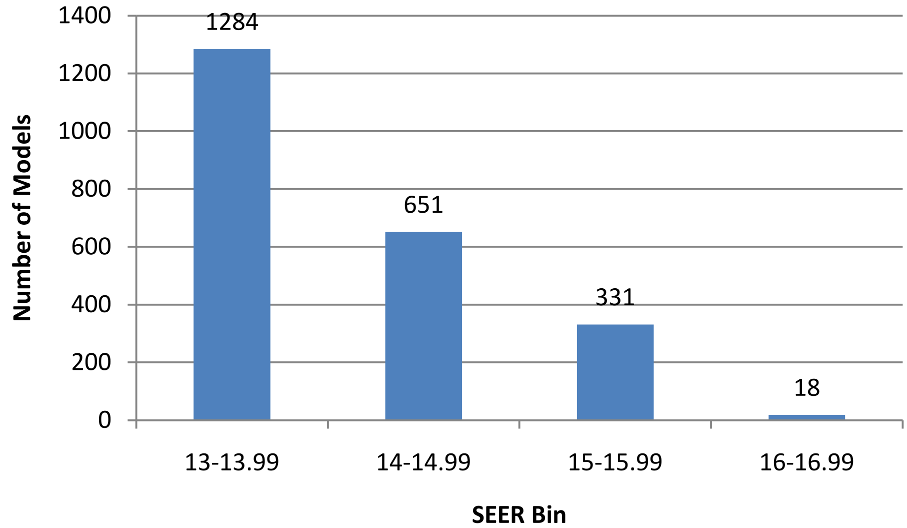

Figure 3.2.10 SEER Ratings for Single Package Central Air Conditioners in the AHRI Certified Product Performance Directory

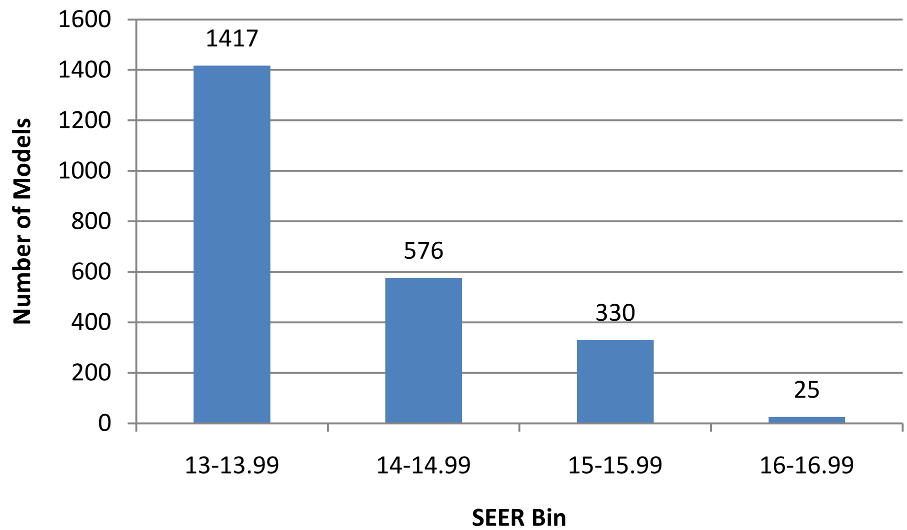

Figure 3.2.11 SEER Ratings for Single Package Heat Pumps in the AHRI Certified Product Performance Directory

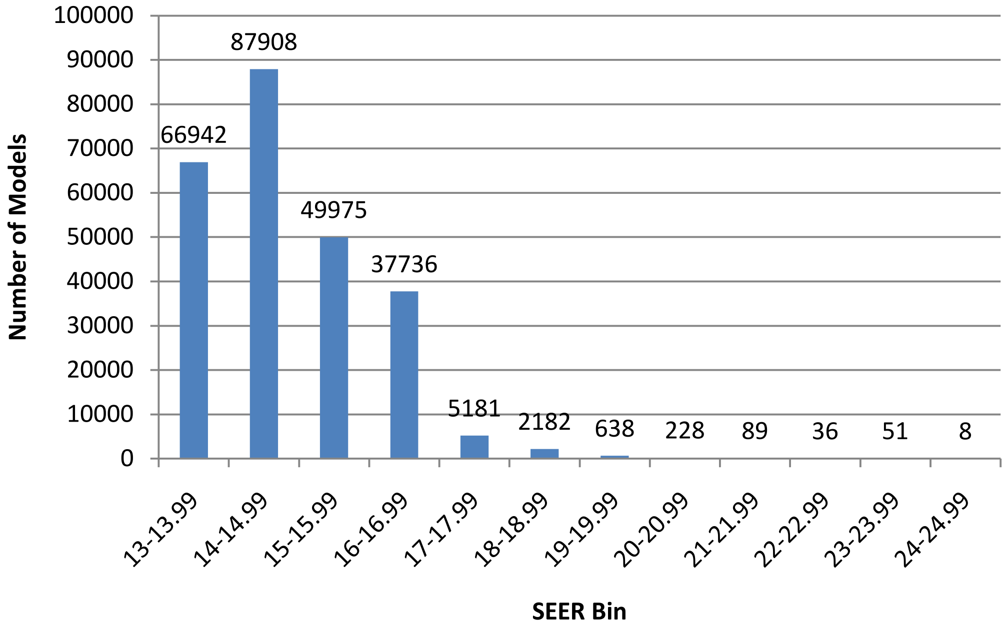

Figure 3.2.12 SEER Ratings for Split System Central Air Conditioners in the AHRI Certified Product Performance Directory

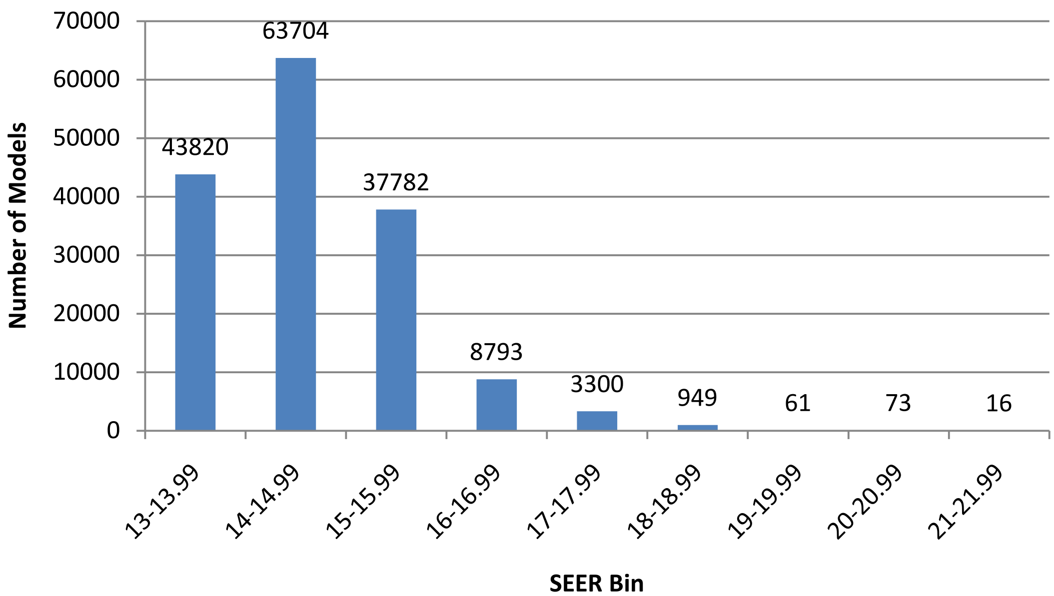

Figure 3.2.13 SEER Ratings for Split System Heat Pumps in the AHRI Directory of Certified Product Performance

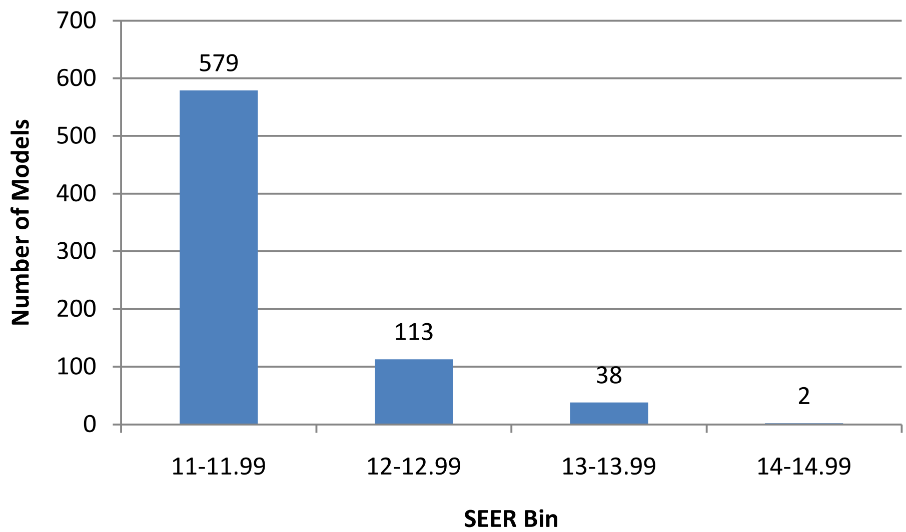

Figure 3.2.14 SEER Ratings for SDHV Systems in the AHRI Directory of Certified Product Performance

Figure 3.2.10 through Figure 3.2.14 show that the SEER Ratings for split system and single package air conditioners and heat pumps are mostly concentrated in the 13 to 14.99 SEER range, although split systems cover a much higher range of efficiencies. The majority of SDHV systems are concentrated in the 11 to 11.99 SEER range. The space constrained products in the AHRI Directory of Certified Product Performance all had a SEER rating of 12.0 (12 central air conditioners and 2 heat pumps).

For heat pumps, DOE also examined the HSPF ratings of the heat pumps in AHRI's Directory of Certified Product Performance. Figure 3.2.15 through Figure 3.2.17 shows the number of single package, split system, and SDHV heat pumps models in the directory that fall into the specified HSPF bins.

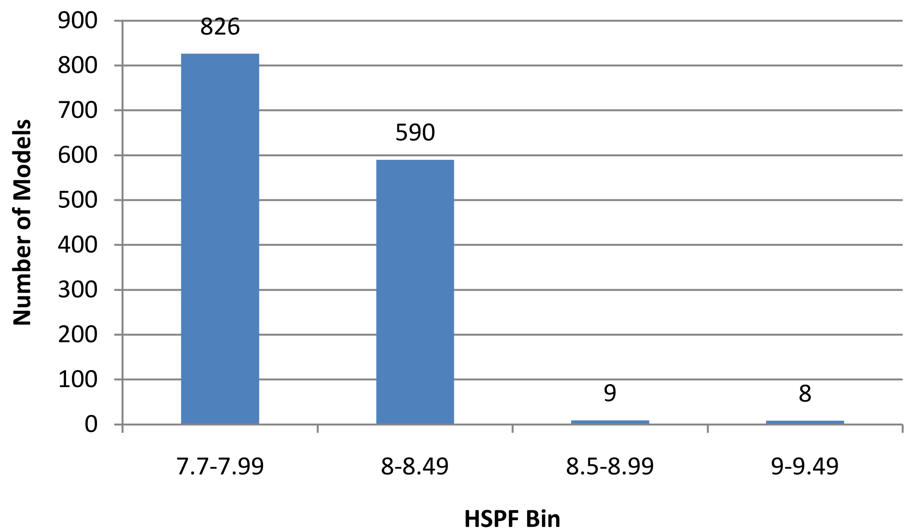

Figure 3.2.15 HSPF Ratings for Single Package Heat Pumps in AHRI's Directory of Certified Product Performance

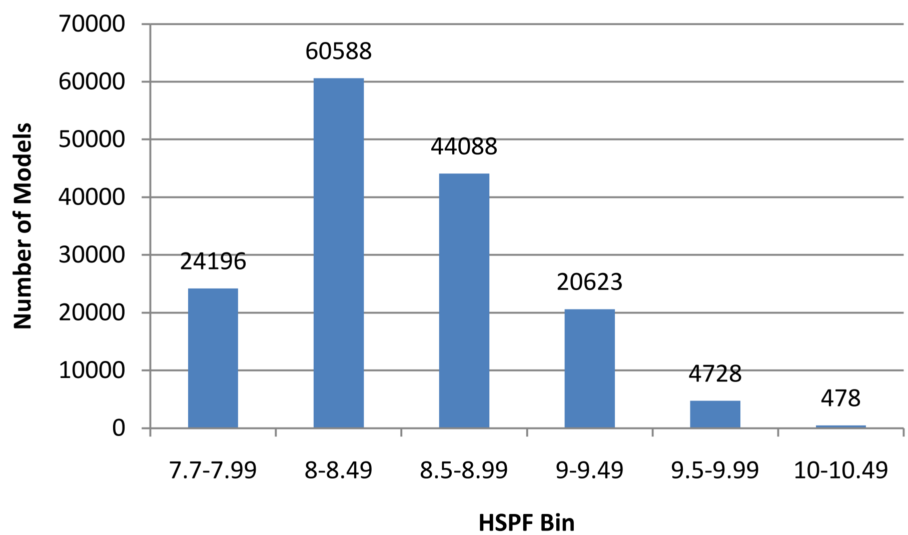

Figure 3.2.16 HSPF Ratings for Split System Heat Pumps in AHRI's Directory of Certified Product Performance

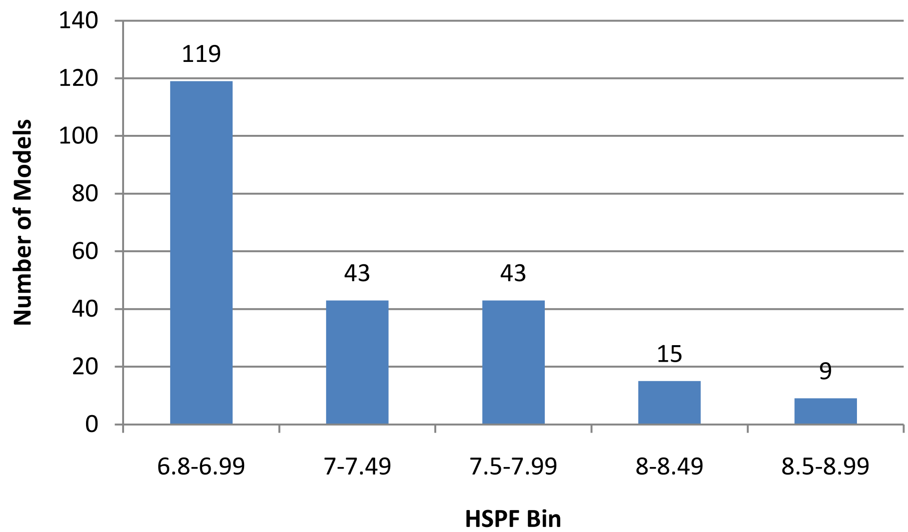

Figure 3.2.17 HSPF Ratings for SDHV Heat Pumps in AHRI's Directory of Certified Product Performance

For single package heat pumps, the HSPF ratings are concentrated in the 7.7 to 8.49 range. Split system heat pumps cover a greater range of HSPF ratings, and are concentrated in the 8 to 8.99 range. For SDHV heat pumps, a significant number of models fall into the range between 6.8 and 7.99. Both space-constrained heat pump models listed in AHRI's directory had an HSPF rating of 7.4.

3.2.8.2 Capacity Data

In characterizing the residential furnace market, DOE also examined the distribution of models by their input capacity ratings. DOE again divided the products into bins based on their input capacities and counted the number of models in each input capacity bin. The capacities were separated into bins in sizes of 5,000 Btu/h. Each bin is named by its upper bound, and each bin's range includes its upper bound but does not include its lower bound (*e.g.*, the 80,000 Btu/h bin includes all values 75,001 Btu/h through 80,000 Btu/h). Figure 3.2.18 through Figure 3.2.21 show these distributions for each product class covered in this rulemaking.

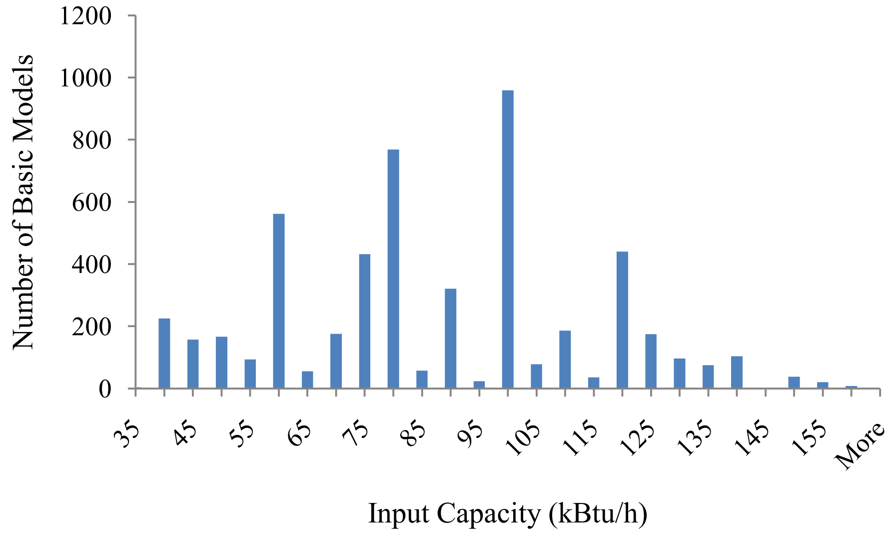

Figure 3.2.18 Distribution of Non-Weatherized Gas Furnace Models by Input Capacity

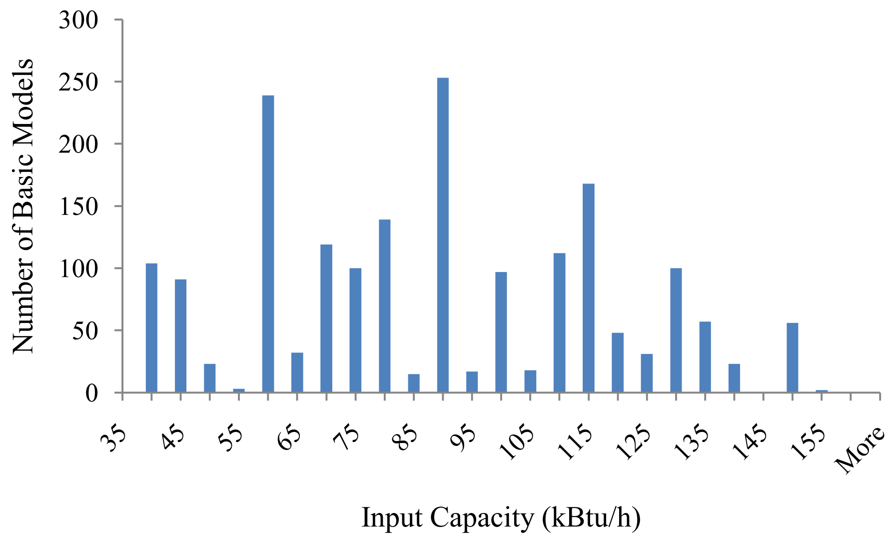

Figure 3.2.19 Distribution of Weatherized Gas Furnace Models by Input Capacity

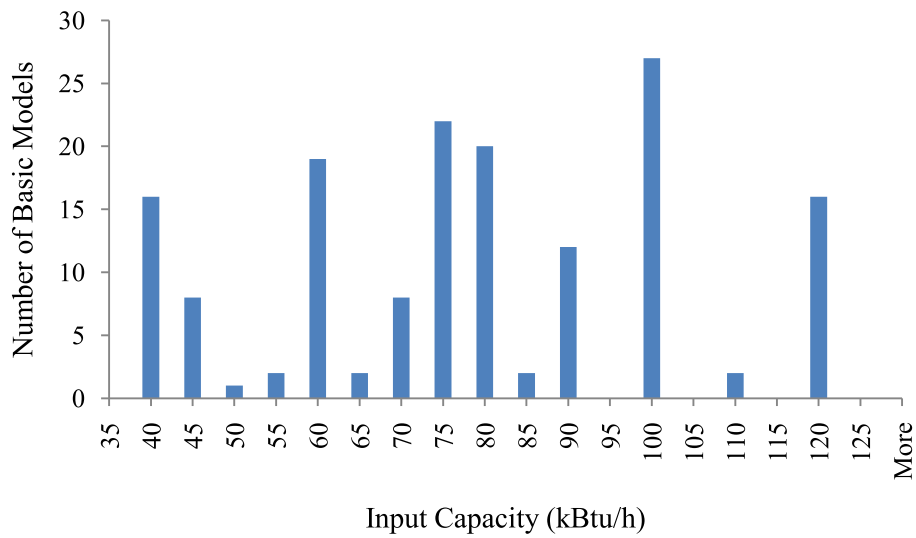

Figure 3.2.20 Distribution of Mobile Home Gas Furnace Models by Input Capacity

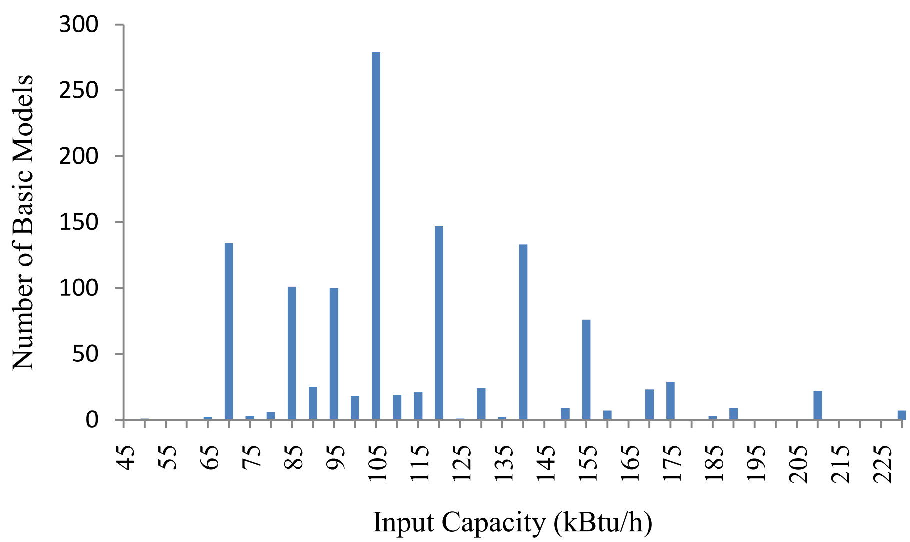

Figure 3.2.21 Distribution of Non-Weatherized Oil-Fired Furnace Models by Input Capacity

Similarly for air conditioners and heat pumps, DOE divided the products into bins based on their cooling capacities and counted the number of models in each cooling capacity bin. The capacities were separated into bins in sizes of 6,000 Btu/h (*i.e.* one half-ton of cooling). Each bin is named by its median, and each bin's range includes its lower bound but does not include its upper bound (*e.g.*, the 24,000 Btu/h bin includes all values from 21,001 Btu/h through 27,000 Btu/h). Figure 3.2.22 and Figure 3.2.23 illustrate these distributions for each product class covered in this rulemaking. Split system air conditioners and heat pumps appear to have "sweet spots" near the three ton cooling capacity (*i.e.* 36,000 Btu/h cooling capacity) where a greater range of average efficiencies occurs, as illustrated by Figure 3.2.22 and Figure 3.2.23, while packaged systems tend to cluster around the three and four ton cooling capacities.

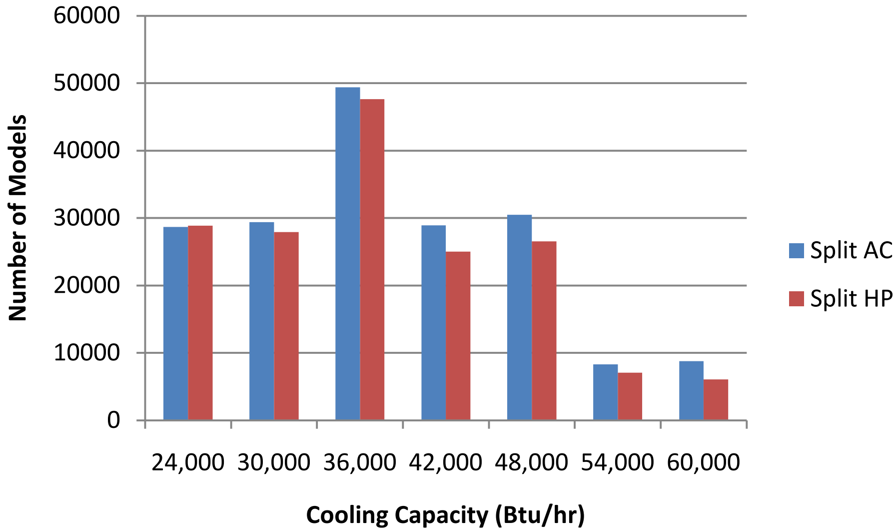

Figure 3.2.22: Number of Models at Selected Cooling Capacities

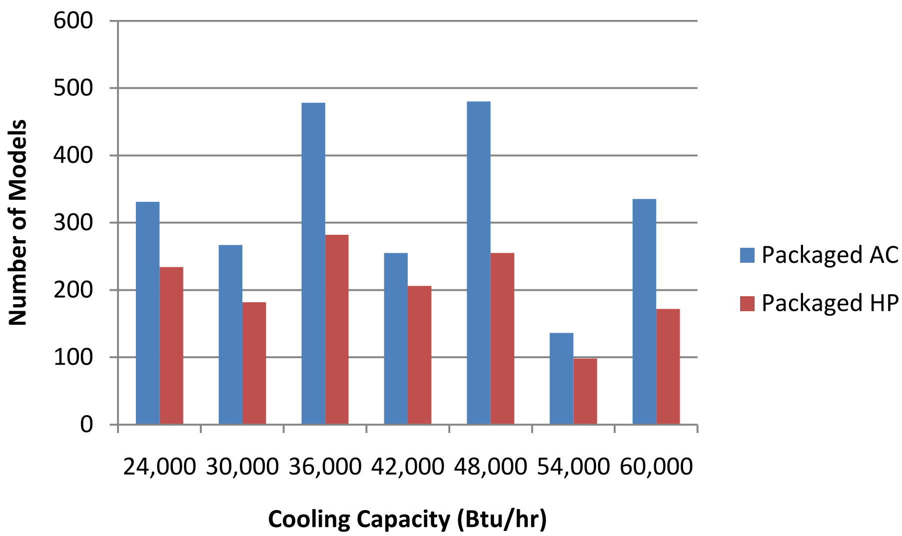

Figure 3.2.23: Number of Models at Selected Cooling Capacities

In reviewing the efficiency of residential central air conditioners and heat pumps currently available on the market, DOE also examined the relationship between efficiency and equipment capacity. Figure 3.2.24 through Figure 3.2.27 show the average SEER ratings at increment of half tons of cooling available for single package and split system air conditioners and heat pumps in AHRI's Directory of Certified Product Performance.

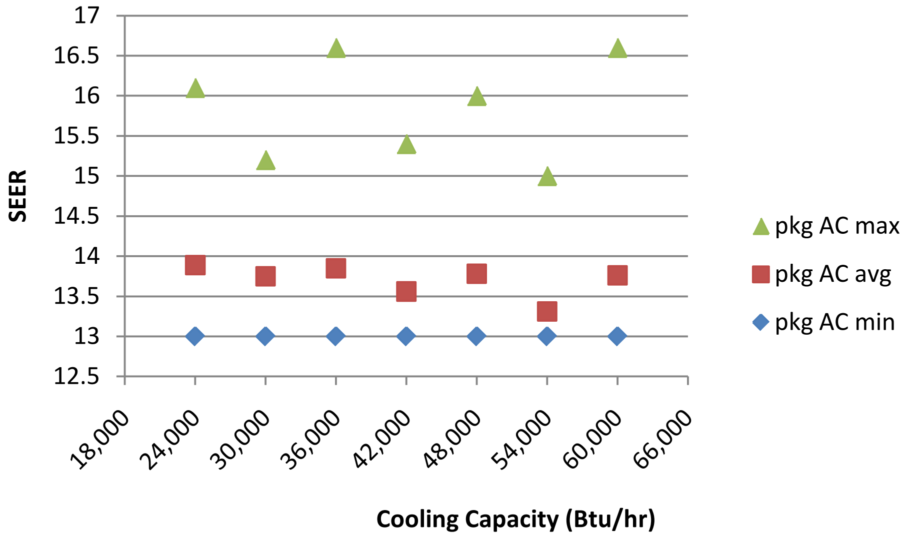

Figure 3.2.24 Average SEER Ratings at Incremental Cooling Capacities for Single Package Air Conditioners in AHRI's Directory of Certified Product Performance

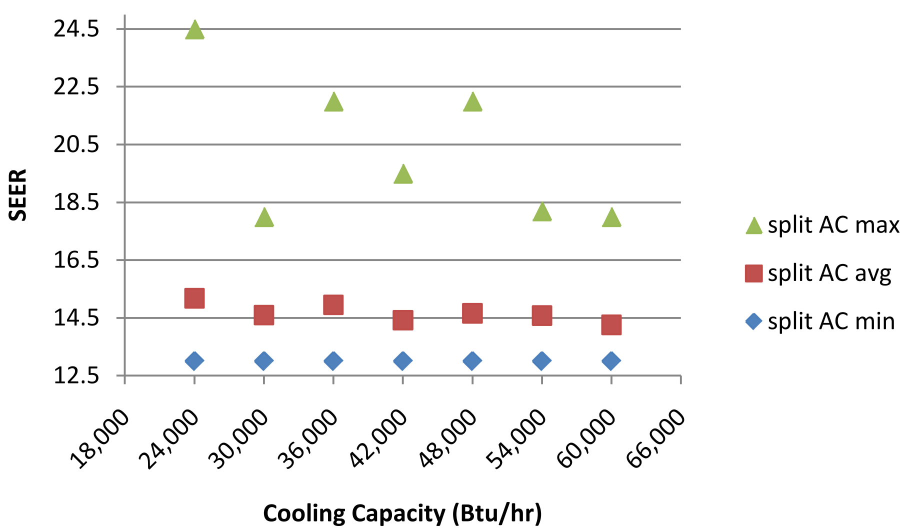

Figure 3.2.25 Average SEER Ratings at Incremental Cooling Capacities for Split System Air Conditioners in AHRI's Directory of Certified Product Performance

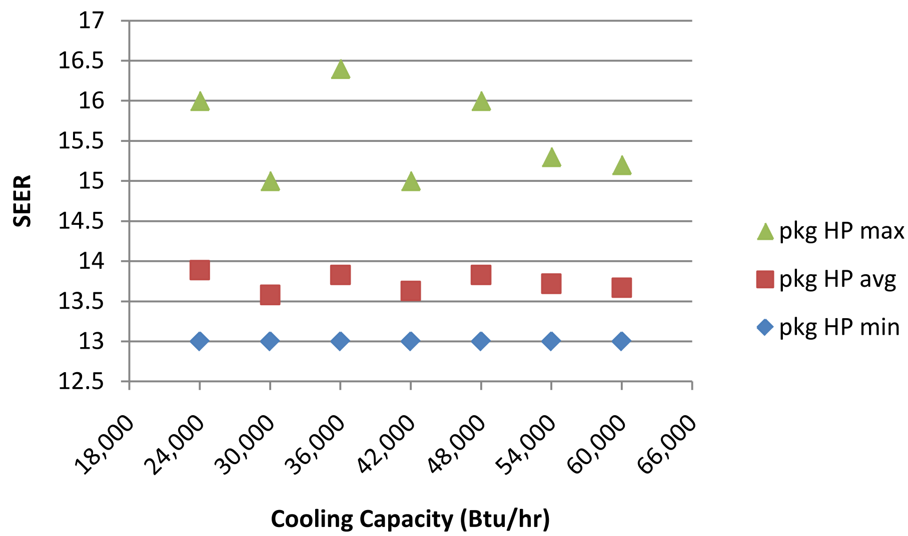

Figure 3.2.26 Average SEER Rating at Incremental Cooling Capacities for Single Package Heat Pumps in the AHRI Directory of Certified Product Performance

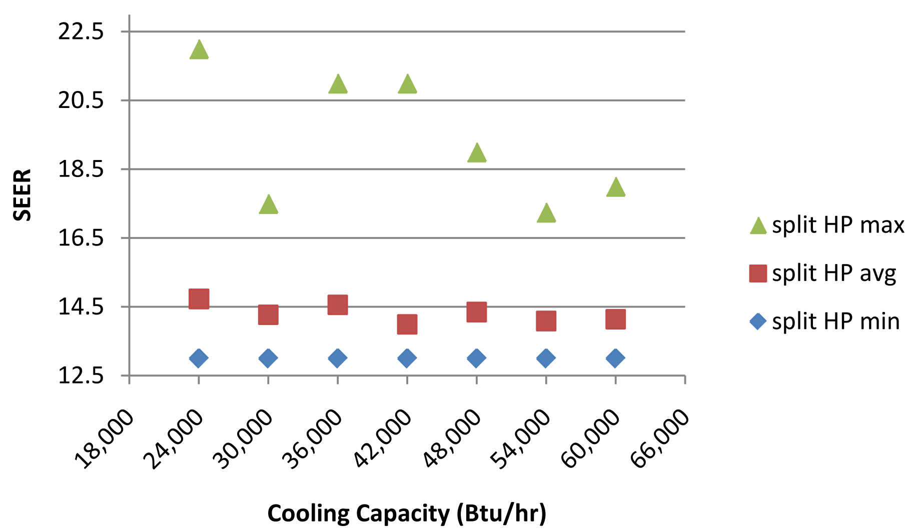

Figure 3.2.27 Average SEER Rating at Incremental Cooling Capacities for Split System Heat Pumps in the AHRI Directory of Certified Product Performance

The average SEER ratings for single package air conditioners and heat pumps are concentrated generally in the 13 to 15 SEER range for the entire range of cooling capacities. Split system air conditioners and heat pumps display a greater range of average SEER ratings at lower cooling capacities, and then appear to become concentrated between 13 and 15 SEER at the higher cooling capacities. Split system air conditioners and heat pumps appear to have "sweet spots" near the three ton cooling capacity (*i.e.,* 36,000 Btu/h cooling capacity) where a greater range of average efficiencies occurs, and where the highest average SEER ratings occur.

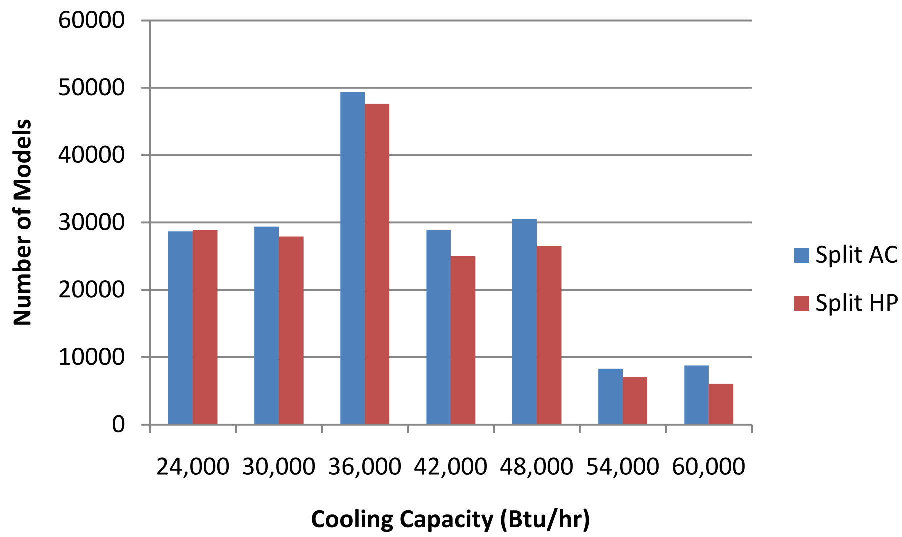

Figure 3.2.28: Number of Models at Selected Cooling Capacities

DOE also examined the average HSPF ratings at each equipment capacity for heat pumps listed in AHRI's Directory of Certified Product Performance. Figure 3.2.29 and Figure 3.2.30 illustrate the average HSPF at each available capacity rating in AHRI's directory for single package and split system. The HSPF ratings for single package heat pumps are consistently between 7.7 and 8.2 HSPF for the entire range of cooling capacities. Split system heat pumps appear to have a greater range of average HSPF ratings at lower cooling capacities, and a smaller range of average HSPF ratings at higher cooling capacities. The average HSPF ratings peak near 3 tons (36,000 Btu/h) and 4 tons (48,000 Btu/h).

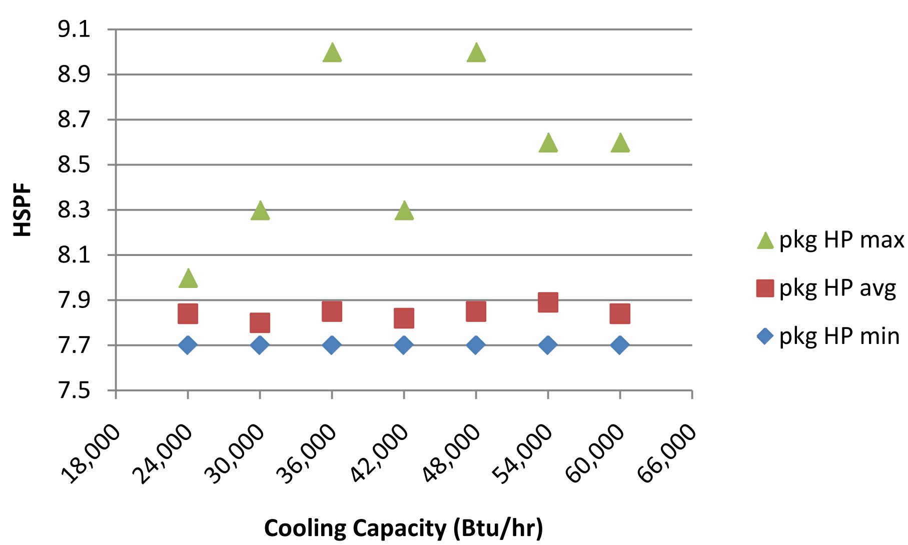

Figure 3.2.29 Average HSPF at Incremental Cooling Capacities for Single Package Heat Pumps in the AHRI Directory of Certified Product Performance

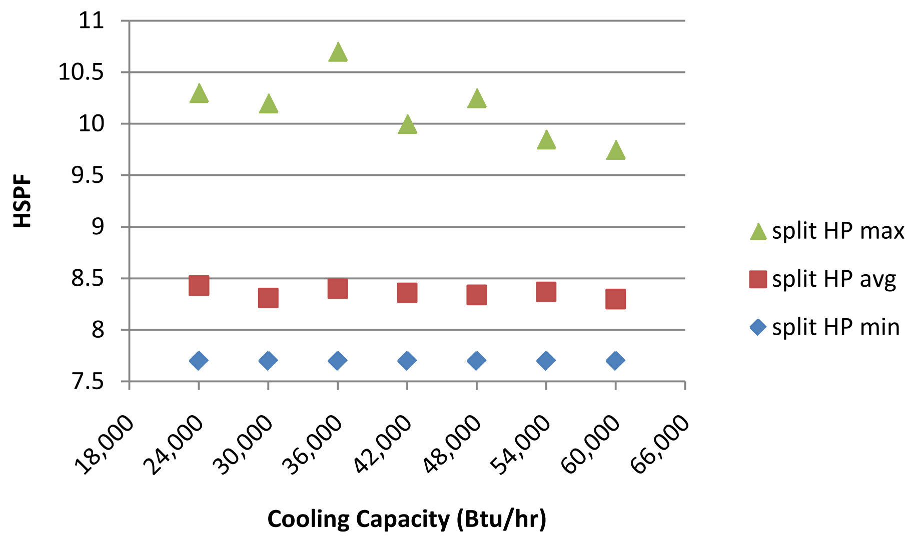

Figure 3.2.30 Average HSPF Rating at Incremental Cooling Capacities for Split System Heat Pumps in the AHRI Directory of Certified Product Performance

The HSPF ratings for single package heat pumps are consistently between 7.7 and 8.2 HSPF for the entire range of cooling capacities. Split system heat pumps appear to have a greater range of average HSPF ratings at lower cooling capacities, and a smaller range of average HSPF ratings at higher cooling capacities. The average HSPF ratings peak near 3 tons (36,000 Btu/h) and 5 tons (60,000 Btu/h). The average HSPF ratings of SDHV heat pumps are between 6.8 and 8 for the entire range of capacities.

Lastly, DOE investigated the relationship between EER and equipment capacity. Figure 3.2.31 through Figure 3.2.34 contain plots of EER compared to equipment capacity in half ton increments for the conventional product classes. The maximum EER values for packaged systems suggest that units are optimized around 2, 3, and 4 tons of cooling, but average values do not necessarily reflect this trend. Plots of this data for split systems did not contain the same peaks and suggest that the optimization of EER for certain tonnages is not as important as other factors.

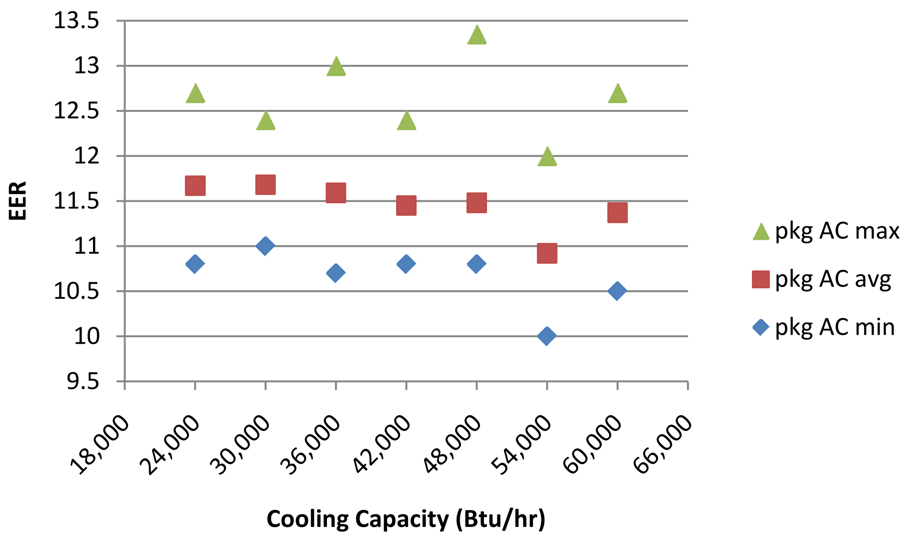

Figure 3.2.31 Average EER Ratings at Incremental Cooling Capacities for Single Package Air Conditioners in AHRI's Directory of Certified Product Performance

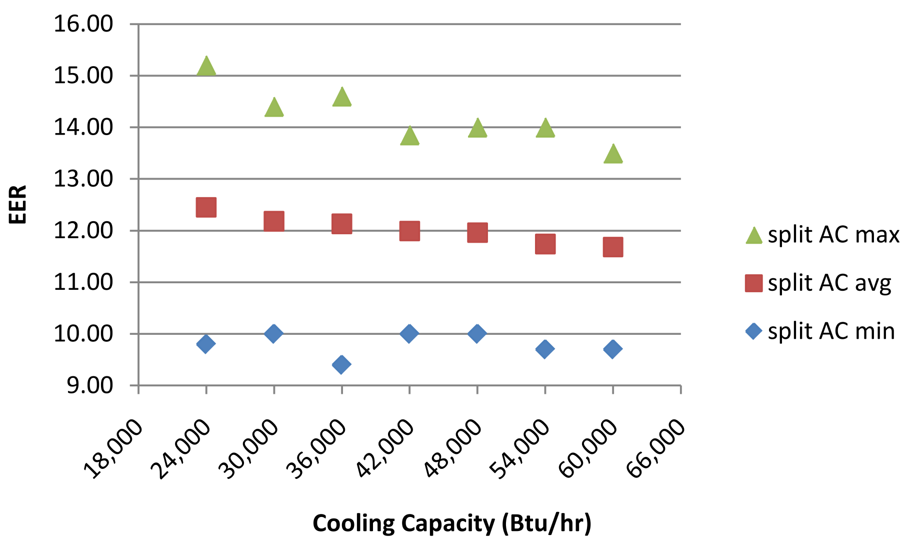

Figure 3.2.32 Average EER Ratings at Incremental Cooling Capacities for Split System Air Conditioners in AHRI's Directory of Certified Product Performance

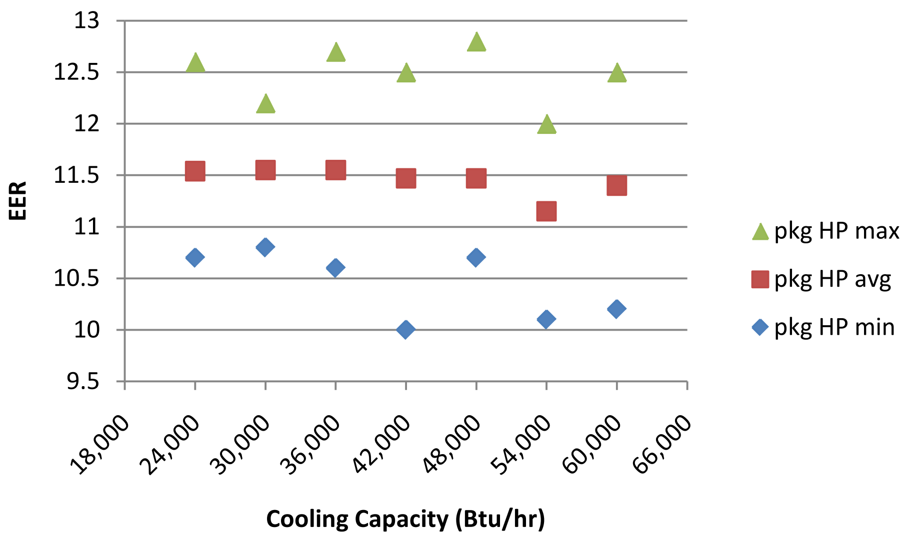

Figure 3.2.33 Average EER Rating at Incremental Cooling Capacities for Single Package Heat Pumps in the AHRI Directory of Certified Product Performance

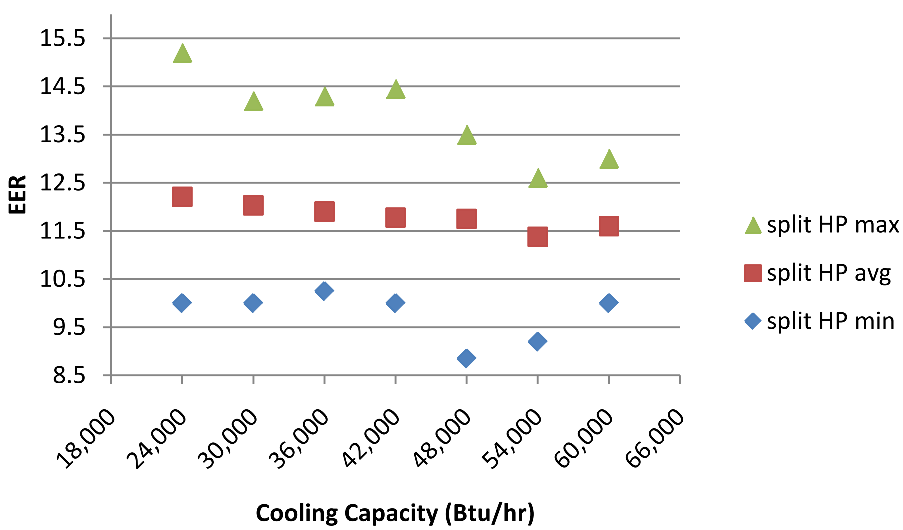

Figure 3.2.34 Average EER Rating at Incremental Cooling Capacities for Split System Heat Pumps in the AHRI Directory of Certified Product Performance

3.2.9 Historical Shipments and Efficiencies

3.2.9.1 Historical Shipments

Information about annual furnace shipment trends allows DOE to estimate the impacts of energy conservation standards on the residential furnace industry. DOE has examined unit shipments and value of shipments using publicly available data from the U.S. Census Bureau's

Annual Survey of Manufacturers (ASM) and Current Industrial Reports (CIR) and estimates from AHRI and *Appliance Magazine*.

Appliance Magazine provides an estimate of annual unit shipments for various appliances, including warm-air gas and oil-fired furnaces. The data, however, does not distinguish between shipments for new construction and replacement. Figure 3.2.35 presents annual shipments of gas and oil-fired residential furnaces (excluding exports) from 2000 to 2009 based on *Appliance Magazine* estimates.[47]

From the data, it is apparent that gas furnaces comprise the vast majority of the residential furnace industry. Shipments of gas furnaces grew steadily until 2005, then plunged in the subsequent four years to 30 percent below the unit shipments at the beginning of the decade. This trend mirrors that of new housing starts, revealing that gas furnace shipments are driven by the new construction market. In contrast, shipments of oil-fired furnaces remained relatively steady over the first part of the decade, before dropping by more than half between 2005 and 2009. This directly corresponds with rising heating oil prices, shown in Figure 3.2.36, which more than doubled in the same period. This strong correlation between shipments and fuel prices indicates that the oil warm-air heating market is driven in large part by replacements.

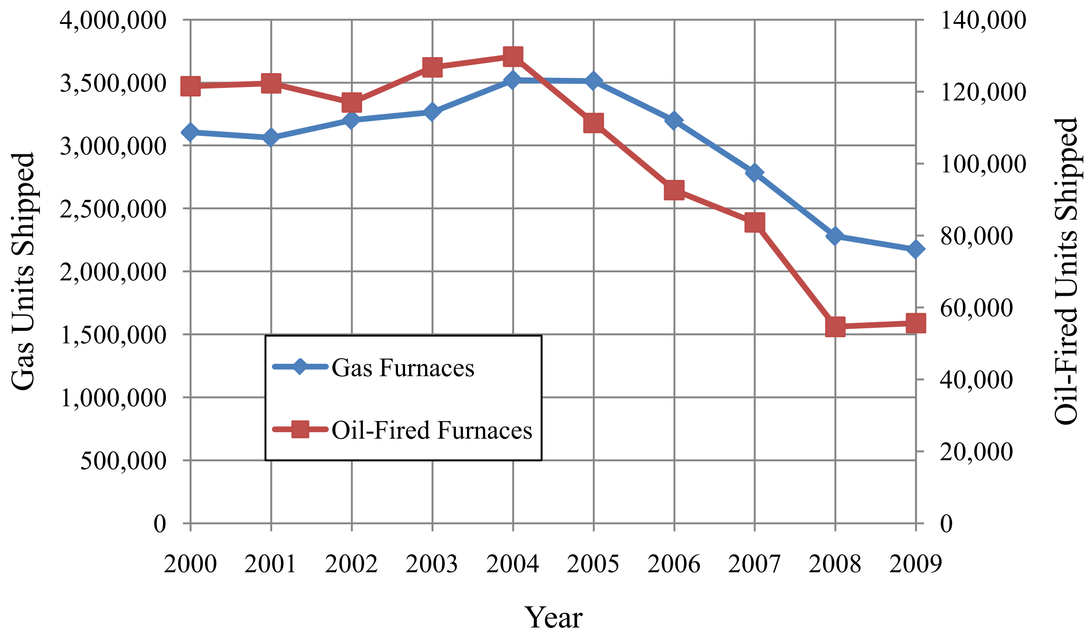

Figure 3.2.35 Residential Furnace Industry Shipments (Domestic and Imported)[48]

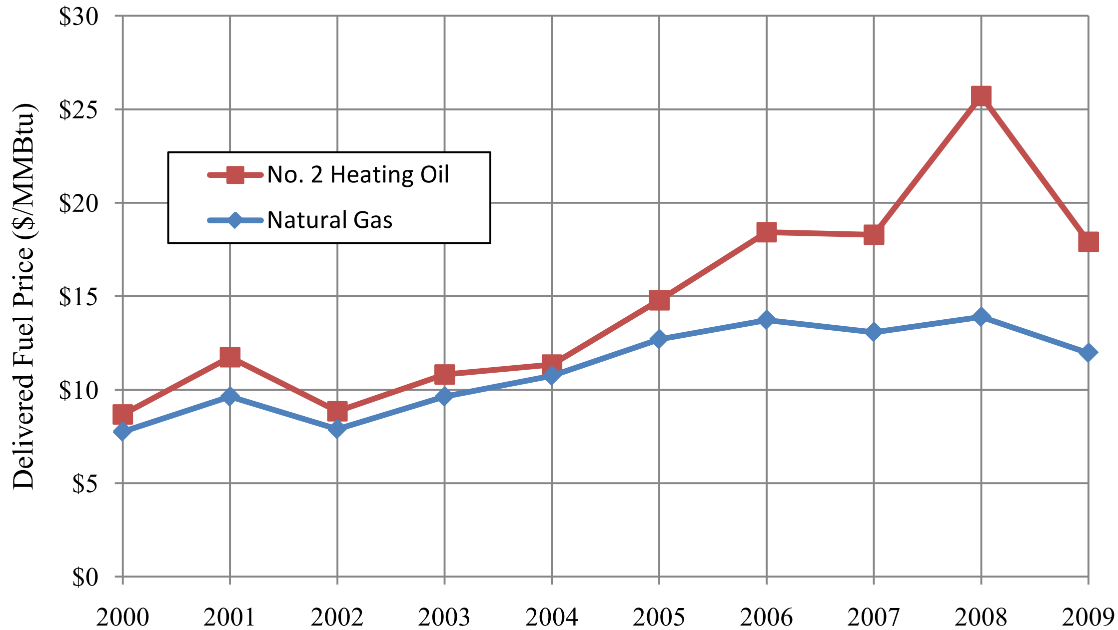

Figure 3.2.36 Average Fuel Prices, 2000 to 2009[49,50,51]

For central air conditioners and heat pumps, AHRI provided historical shipments data over the 1990-2009 time-period disaggregated into the four primary product classes.[52] Historical shipments from 1972-1989 were also provided by AHRI from previous data submittals to the Lawrence Berkeley National Laboratory (LBNL).[53] The data for 1972-1989 included some shipments of 3-phase as well as single-phase central air conditioners and heat pumps, whereas the data for 1990-2009 included only single-phase central air conditioners. DOE disaggregated the shipments for single-phase and 3-phase central air conditioner and heat pump equipment in the earlier data and included only single phase units. Table 3.2.23 summarizes the historical shipments data.

Table 3.2.23 Central Air Conditioner and Heat Pump Shipments

Year	Split CAC *thousands*	Single Package CAC *thousands*	Split HP *thousands*	Single Package HP *thousands*
1972	1,489	257	28	52
1973	1,742	318	35	52
1974	1,503	289	49	48
1975	888	159	83	45
1976	1,219	231	177	74
1977	1,364	218	329	89
1978	1,546	253	389	97
1979	1,428	248	376	107
1980	1,233	134	293	61
1981	1,293	122	348	66
1982	1,037	111	267	49
1983	1,558	192	455	82
1984	1,857	189	535	98
1985	1,784	203	619	107
1986	1,876	203	680	106
1987	2,204	237	714	103
1988	2,334	247	649	91
1989	2,516	267	650	91
1990	2,241	334	643	104
1991	2,388	306	615	96
1992	2,254	330	647	101
1993	2,474	346	718	107
1994	3,087	387	825	118
1995	3,221	384	834	120
1996	3,635	418	936	139
1997	3,364	395	917	142
1998	4,010	406	1,019	148
1999	4,317	429	1,044	147
2000	4,280	437	1,073	159
2001	3,931	361	1,180	165
2002	4,381	380	1,229	165
2003	4,281	390	1,350	174
2004	4,561	414	1,584	190
2005	5,461	455	1,810	213
2006	4,038	330	1,807	190
2007	3,582	338	1,570	199
2008	3.171	274	1,566	189
2009	2,887	234	1,389	162

Source: Air-Conditioning, Heating, and Refrigeration Institute (AHRI)

3.2.9.2 Value of Shipments

Table 3.2.24 and Table 3.2.25 provide the value of shipments for the residential furnace and residential central air conditioner and heat pump industries from 2005 to 2009 using the U.S. Census Bureau CIRs.[54] The CIR expresses all dollar values in current dollars (*e.g.*, 2005 data are expressed in 2005$). Using the gross domestic product (GDP) deflator, DOE converted each year's shipment values to 2009$; 2009 was the last year included in the CIR data set.

Table 3.2.24 Value of Residential Furnace Shipments by Year[55]

Year	Value of Shipments *$, millions*	Value of Shipments in 2009$ *$, millions*
2009	1,916	1,916
2008	1,826	1,863
2007	2,090	2,173
2006	2,205	2,331
2005	2,268	2,434

Table 3.2.25 Value of Residential Central Air Conditioner and Heat Pump Shipments by Year[56]

	Air Conditioners		Heat Pumps	
Year	**Value of Shipments** *$, millions*	**Value of Shipments in 2009$** *$, millions*	**Value of Shipments** *$, millions*	**Value of Shipments in 2009$** *$, millions*
2009	6,247	6,247	2,191	2,191
2008	6,994	7,136	2,000	2,041
2007	7,603	7,905	2,030	2,111
2006	7,402	7,825	1,987	2,101
2005	6,979	7,490	1,869	2,006

From these data it is apparent that the residential furnace industry has gradually been shrinking in proportion to new housing starts since 2005. The residential central air conditioner portion of the central air conditioner and heat pump industry has been shrinking since 2007, but the heat pump industry has increased slightly.

3.2.9.3 Historical Efficiencies of Central Air Conditioners and Heat Pumps

AHRI provided historical shipment-weighted efficiency data (SWEF) data spanning the years 1992 to 2009.[28] Between1992, the year in which the first set of standards for central air conditioners and heat pumps became effective; and 2006, when an updated set of standards became effective, the SWEFs for central air conditioners grew by approximately one SEER point. Figure 3.2.37 shows the SWEFs for split system and single package central air conditioners. For 1992-2005 and 2007 to 2009, linear fits provide a good estimate of the SWEF growth rate. The updated standards caused a jump in SWEF for 2006 and 2007, but by 2008 the SWEF growth rate returned to a level slightly above the SWEF growth from 1992 to 2005. However, the SWEF growth rate for packaged air conditioners remained significantly higher than the split-system SWEF for 2007 to 2009. Table 3.2.26 provides a summary of the SWEF growth rates for each product class.

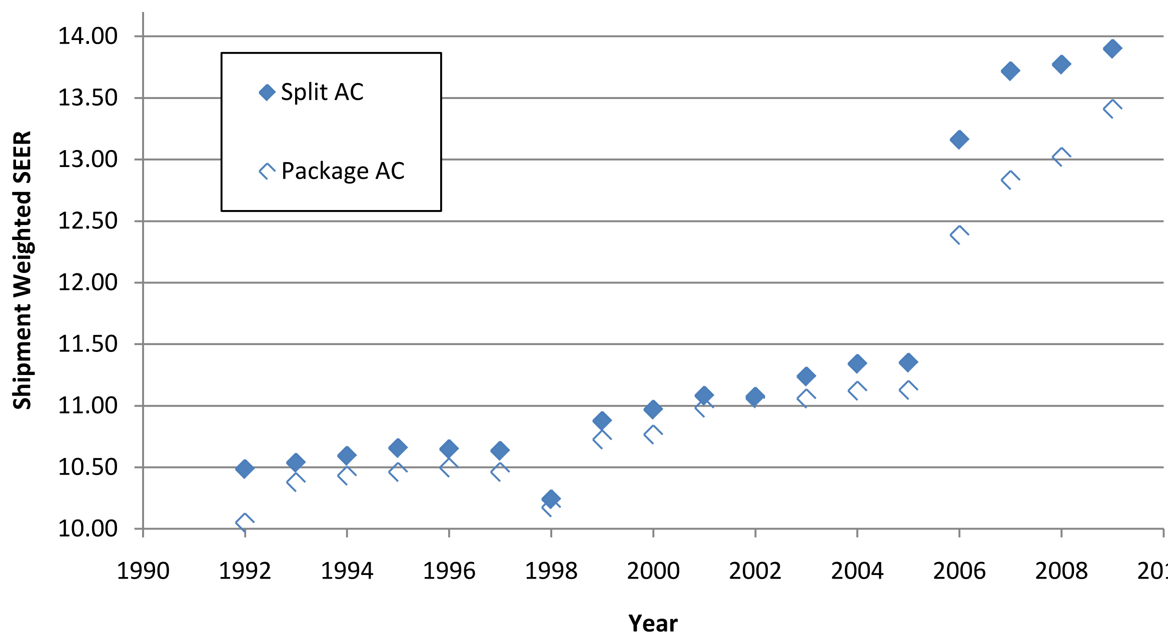

Figure 3.2.37 Central Air Conditioner Historical Shipment-Weighted Efficiencies[o]

Table 3.2.26 Central Air Conditioner Shipment-Weighted Efficiency Growth Rates

	SWEF Growth Rate (*SEER increase per year)*	
Product Class	***1992-2005***	***2007-2009***
Split system air conditioners	0.0703	0.0900
Single package air conditioners	0.0778	0.2900

For heat pumps shipped between 1992 and 2006, the SEER-based also grew by approximately one SEER point. Figure 3.2.38 shows the SEER-based SWEFs for split system and single package heat pumps. . Table 3.2.27 provides a summary of the SEER-based SWEF growth rates for each product class. The growth rates for both split and packaged systems were

[o] Source: Air-Conditioning, Heating, and Refrigeration Institute (AHRI).

much higher for 2007 to 2009, as compared to the rest of the timeline. Similar to air conditioners, the packaged heat pumps exhibited a higher SWEF growth rate than the split systems. AHRI did not provide historical SWEF data for heat pump HSPFs.

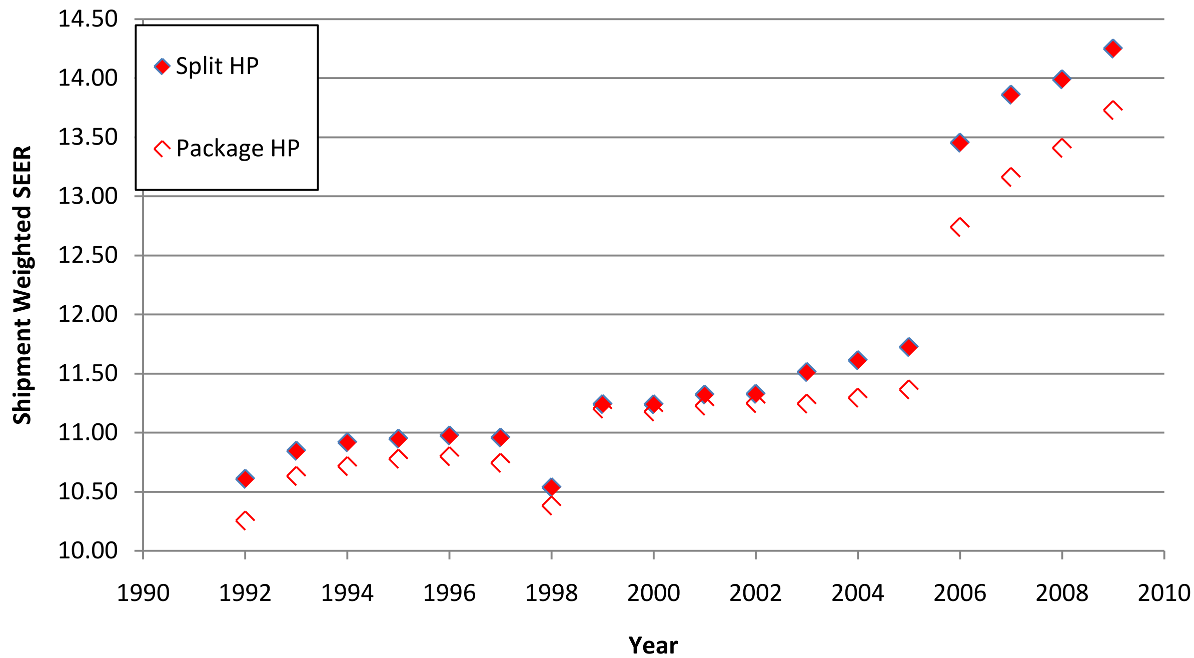

Figure 3.2.38 Heat Pump Historical Shipment-Weighted Efficiencies base on SEER[p]

Table 3.2.27 Heat Pump Shipment-Weighted Efficiency Growth Rates

	SWEF Growth Rate *SEER increase per year*	
Product Class	***1992-2005***	***2007-2009***
Split system heat pumps	0.0739	0.1950
Single package heat pumps	0.0736	0.2850

3.2.10 Saturations in U.S. Households

Stock saturation refers to the percentage of the housing stock equipped with a given product or exhibiting a certain feature. As of 2005, 46.4 percent (51.6 million) of homes in the United States have central warm-air furnaces.[57] Of these furnaces, 44.7 million are gas furnaces, 2.8 million are oil-fired furnaces, and 4.1 million are liquid petroleum gas (LPG) furnaces. Site energy consumption attributable to residential warm-air space heating is 46.0% (5.37 quads) of total U.S. energy consumption.[58] Within individual homes, warm-air space heating represents, on average, 42.7% percent (40.5 million Btu) of total annual household energy consumption.[59] The

[p] Source: Air-Conditioning, Heating, and Refrigeration Institute (AHRI)

American Housing Survey (AHS) provides historical stock saturations for central air conditioning and heat pump equipment for every other year between 1991–2007. [60] Table 3.2.28 summarizes the saturations for central air conditioners, heat pump, and both types of equipment. Central air conditioners and heat pump saturation has grown from 38.6 percent to 64.6 percent from 1991 to 2007.

Table 3.2.28 Central Air Conditioner Heat Pump Historical Housing Stock Saturations

Year	CAC	HP	Total
1991	30.8%	7.8%	38.6%
1993	32.0%	8.5%	40.5%
1995	33.9%	9.1%	43.0%
1997	36.3%	12.0%	48.3%
1999	41.4%	11.4%	52.8%
2001	45.0%	11.3%	56.3%
2003	46.5%	11.7%	58.2%
2005	50.2%	12.7%	62.9%
2007	51.8%	12.8%	64.6%

3.3 FURNACE TECHNOLOGY ASSESSMENT

The purpose of the technology assessment is to develop a list of technology options that manufacturers can use to improve the efficiency of residential furnaces. The following assessment provides descriptions of those technology options that apply to all product classes.

In preparation for the screening and engineering analyses, DOE identified several possible technology options and examined the most common efficiency-improving technologies used today. These technology options provide insight into the technological improvements typically used to increase the energy efficiency of residential furnaces.

3.3.1 Furnace Characterization

At a basic level, furnaces are characterized based on their whether they are weatherized, whether they are designed for condensing operation, and the physical configuration of the heat exchanger and blower.

3.3.1.1 Weatherization

Residential furnaces can be described as either weatherized or non-weatherized furnaces. Weatherized furnaces are generally installed outdoors (often on rooftops), and non-weatherized furnaces are installed indoors. The main difference between a weatherized furnace and a non-weatherized furnace is that the weatherized furnace has a weather-resistant external case, while the non-weatherized furnace does not. Weatherized furnaces are only used as part of unitary heating and cooling units, which means that an air conditioner is contained in the same package. DOE does not know of any manufacturer that presently sells a stand-alone furnace approved for outdoor installation. Manufacturers produce very few weatherized oil-fired furnaces.

Because weatherized furnaces are subject to adverse weather conditions, the heat loss through the jacket of a weatherized furnace is higher than that of a non-weatherized furnace. To account for this, the DOE test procedure requires manufacturers to rate weatherized furnaces for outdoor installation; they do so by applying a higher multiplication factor to the jacket losses in order to simulate outdoor conditions.

The DOE test procedure specifies that all non-weatherized furnaces shall be rated and tested as isolated combustion systems (ICS), which means that the furnace is isolated from the heated space and draws combustion and dilution air, if applicable, from the outdoors. Because all non-weatherized furnaces are rated under the same conditions, those that are installed in the heated space do not have a rated AFUE advantage over those that are installed outside of the heated space, such as non-weatherized furnaces installed in garages, due to their jacket losses. However, in real-world applications, conductive heat transfer through the jacket of a non-weatherized furnace installed in the heated space will dissipate as useful heat to the heated space. This means that non-weatherized furnaces installed in the heated space may be able to realize higher operational efficiencies as compared with their ratings.

3.3.1.2 Condensing Operation

Non-weatherized furnaces can be either non-condensing or condensing. When the flue gas temperature is substantially higher than the water vapor dew point and the latent heat (the heat from condensation of water vapor in the combustion products) is not recovered in the appliance's heat exchanger, the furnace is classified as non-condensing. The annual fuel utilization efficiency (AFUE) of such furnaces is generally below 82 percent AFUE for natural gas furnaces and 88 percent AFUE for oil-fired furnaces. Condensing furnaces recover more heat from the combustion products by condensing the water vapor in the flue gases. There are no condensing weatherized furnaces available on the furnace market primarily because of concerns that the condensate could freeze and damage the furnace.

As water vapor begins to condense in the furnace's heat exchanger, the latent heat recovered from the vapor raises the furnace's AFUE to above 90 percent, with a higher AFUE indicating a greater amount of condensation being formed. Condensing furnaces typically require additional components, such as a corrosion-resistant secondary heat exchanger and a condensate drain device. Condensing furnaces also cannot use a natural draft venting system, since the buoyancy of the cooler flue gases is not sufficient to draw the gases up a regular chimney. Forced and induced draft blowers are used in conjunction with condensing furnaces to draw air into the combustion zone and exhaust the flue gases through the vents.

Furnaces generally are not manufactured in the 82 to 89 percent AFUE range. In this range, corrosive condensate can form in the vent system under certain operating conditions, which can cause safety concerns in venting systems used for non-condensing furnaces (*i.e.*, Category I and Category III venting). However, the temperature of the flue gases is still too high at these efficiencies to allow for the use of polyvinylchloride (PVC) for the venting system. Proper venting of such a furnace requires a special stainless steel venting system, which is often cost prohibitive. As a result, manufacturers typically do not offer products in this range of efficiencies.

3.3.1.3 Configurations

Three different airflow configurations are commonly used in residential furnaces: 1) horizontal; 2) upflow; and 3) downflow or counterflow. A fourth design, called multipoise or multiple direction, allows the furnaces to be set up in two or three of the previously listed configurations depending on the installation requirements. Each configuration requires a different arrangement of the furnace's basic components.

The horizontal furnace configuration is commonly used in attics, crawl spaces, and other locations where the height of the furnace is the constraining dimension. Air enters at one end of the unit through the blower compartment, is forced horizontally over the heat exchanger, and then exits the furnace at the opposite end through installed ductwork that distributes it to the heated space. Horizontal furnaces are most common in weatherized (especially rooftop) units.

The upflow "highboy" configuration is most commonly used for basement or first-floor equipment room installations where floor space is at a premium. In this configuration, the blower is located below the heat exchanger. Air enters at the bottom or lower side of the unit and leaves at the top through a warm-air outlet (plenum). The upflow "lowboy" furnace configuration occupies more floor space and is lower in height than the upflow highboy design, which makes it suited for basement installations where both floor space and height are constraints. In the upflow lowboy configuration, manufacturers place the blower alongside the heat exchanger. A return-air plenum is installed above the blower compartment, and a supply-air plenum is installed above the heat exchanger compartment. Upflow highboy configuration is most common in non-weatherized gas and oil-fired furnaces.

The downflow, or counterflow, configuration is used in houses that have an under-the-floor type of heat distribution system, where the ductwork that delivers heated air is located beneath the conditioned space. In this configuration, the blower assembly is located above the heat exchanger, and the return-air plenum is connected to the top of the unit. Most mobile home furnaces are installed in the downflow configuration.

The multipoise, or multiple-direction, furnace design allows for the unit to be configured as upflow, horizontal, or downflow, depending on the requirements of the particular installation. Some multipoise furnaces are able to be configured in all three configurations (*i.e.*, upflow, horizontal, and downflow), while others are only designed to be set up in two of the three configurations (*e.g.,* upflow and horizontal). Demand is growing for these products because they allow for more flexibility and can accommodate different types of installations. Multipoise appliances are more expensive to manufacture because they require extensive testing and more complicated controls. The majority of modern non-weatherized furnaces are multipoise.

Shipments data from AHRI show that multipoise furnaces account for approximately two-thirds of total shipments. Upflow designs account for 25 percent, and downflow and horizontal designs together account for just 9 percent.

3.3.2 Baseline Product Components and Operation

A basic residential gas furnace comprises a hot surface or direct spark ignition system, tubular inshot burners, non-condensing heat exchanger, single-speed air blower assembly with PSC motor and forward swept blades, single-speed mechanical draft combustion fan assembly, and automatic controls. A basic residential oil furnace comprises an interrupted spark ignition system, flame retention power burner, non-condensing heat exchanger, and a single-speed air blower assembly.

3.3.2.1 Heat Exchanger

The heat exchanger's function is to transfer heat from the combustion gases to the circulating air, which is then distributed to the heated space. The heat exchanger of a baseline unit is usually constructed from aluminized, cold-rolled steel or stainless steel with welded or crimped seams. There are two types of primary heat exchangers commonly used in residential furnaces: individual-section and drum.

Individual-section heat exchangers consist of a number of separate heat exchanger sections. Each section has an individual fuel-burning device. The sections are typically joined together at the upstream end of the heat exchanger so that a common ignition device can light all of the burners. The sections are also joined together at the downstream end to direct flue gases to a common flue. The individual-section type of heat exchanger is used primarily in gas-burning products.

Tubular and clamshell heat exchangers are different types of the individual-section heat exchanger. A tubular heat exchanger comprises several metal tubes bent in shape, while the clamshell, or serpentine, heat exchanger is manufactured by folding specially-formed sheets of thin metal. Heat exchanger designs differ from manufacturer to manufacturer, but are typically similar across all product lines for a specific manufacturer. Tubular heat exchangers require a smaller initial investment than clamshell types, but can be more costly if produced in high volume.

Drum heat exchangers have a single combustion chamber and use a single-port fuel-burning device. The drum heat exchanger is used primarily in oil-firing units and occasionally in mobile home gas furnace designs. All oil-fired units use drum heat exchangers.

3.3.2.2 Burner Assembly

Gas Burners. The gas burner assembly in a residential furnace functions to: (1) control and regulate the flow of gas, (2) ensure the proper mixture of gas with air, and (3) ignite the gas under safe conditions. To accomplish these functions, a gas burner assembly consists of four major parts or sections: a gas valve, an ignition device, a manifold and orifice(s), and gas burners and adjustments.

The gas valve consists of a number of parts—a hand shutoff valve, a pressure-reducing valve, safety shutoff equipment, and an operator-controlled automatic gas valve—each performing a different function. In modern units, these parts are all contained in a combination gas valve (CGV).

The manifold connects the gas supply from the gas valve to the burners and delivers gas in equal proportions to each burner. The orifices permit a high-velocity stream of gas to enter the burners and meter the gas flow.

Gas-burning devices require the correct mixture of air (*i.e.*, oxygen) and gas to be supplied to ensure complete combustion. Primary air, which is mixed with the gas prior to combustion, accounts for 30 to 50 percent of the total air required for stoichiometric combustion. Secondary air, which is supplied to the flame at the time of combustion, provides the remaining 50 to 70 percent of the total air supply to prevent the formation of noxious carbon monoxide. To produce efficient and safe combustion, it is essential to maintain the proper ratio of primary to secondary air. In gas furnaces, the burners are typically "inshot" (*i.e.*, single-port), which means that one long flame is directed into the heat exchanger section after ignition. The fuel enters the burner through a venturi tube that accelerates the gas stream. In turn, the high velocity of the gas stream creates a suction effect that entrains the primary air into the tube and mixes it with gas from the gas service line. This mixture of gas and primary air oxidizes in the first stage of combustion. In the second stage of combustion, secondary air is introduced to the combustion zone in excess to burn the remaining gas.

Oil Burners. In an oil-fired furnace, the oil burner is typically a flame retention head burner, also known in the industry as a high-pressure, atomizing burner. This burner forces oil at a pressure of 100 pounds per square inch gauge (psig) through the nozzle, breaking the oil into fine, mist-like droplets. Some models require operating oil pump pressures in the 140 to 200 psig range. Vanes supply combustion air to a low-pressure area created by the atomized oil spray. These supply vanes create turbulence and facilitate mixing of the air and fuel.

The main components of a high-pressure, atomizing burner are the power assembly (fuel pumps, motor, fan, and air shutters) and the nozzle assembly. All high-pressure burners have electronic ignition. A step-up transformer supplies the power to two electrodes, which causes a spark to jump. The force of the air in the blast tube causes the spark to arc into the oil-air mixture, thereby igniting it.

3.3.2.3 Electronic Ignition

Modern furnaces are equipped with electronic ignition systems, which light the burner with an electrical component upon a call for heat. Unlike standing pilot ignition systems that consume fuel continuously, electronic devices and their control modules (which house electronic circuitry required to control the ignition system) operate only during the active mode. The different types of electronic ignition systems are discussed in greater detail below.

Hot Surface Ignition (HSI). Hot surface ignition (HSI) is the most common form of electronic ignition in gas furnaces and the baseline ignition component for non-weatherized gas furnaces and mobile home gas furnaces. The igniter in this system is an electrically heated resistance element that thermally ignites the main burner directly, without use of a pilot light. Hot surface igniters use simpler controls and are regarded in the industry as being more reliable than other types of electronic ignition. In HSI operation, a voltage is applied to the igniter until its surface is sufficiently hot to light the system's main burner directly. Silicon nitride igniters offer a durability advantage over silicon carbide, and as a result they have largely replaced silicon carbide igniters in most modern furnaces.[61]

Direct Spark Ignition (DSI). This type of ignition system provides the same functionality as a hot surface igniter: it serves to ignite the main burner and acts as a flame sensor. As its name implies, the DSI lights the main burner directly by generating a spark. There is no pilot light. Flame rectification is used to detect flame presence: if a flame is present, the control module will hold the gas valve open and cut off power to the igniter. If a flame has not been established within the trial-for-ignition period (approximately 4 to 7 seconds), the system will go into lockout and must be reset. Direct spark igniters are the baseline ignition component for weatherized gas furnaces, which DOE is not analyzing in this rulemaking, as discussed in section III.G.2.a of the final rule.

Intermittent Pilot Ignition. This is a device that lights a pilot by generating a spark. The pilot light in turn lights the main burner. DOE could not identify any intermittent pilot ignition systems that have been incorporated into today's furnace designs.

Interrupted Duty Ignition Systems. All modern oil burners have a type of electronic ignition called interrupted duty ignition. A step-up transformer supplies power to two electrodes, which causes a spark to jump. The force of the air in the blast tube causes the spark to arc into the oil-air mixture, thereby igniting it. The interrupted duty ignition system for an oil burner activates the spark only until either a steady flame is established or the end of a timed trial-for-ignition (TFI) period.

3.3.2.4 Mechanical Draft

Modern furnaces in all product classes employ mechanical draft, in which motorized fans to supply and regulate air for combustion and create sufficient draft to exhaust the flue gases. The fan is typically driven by a single-speed, two-speed, or variable-speed motor in the 75 to 90 watt range. [62]

Mechanical draft systems can be designed as either induced draft (*i.e.*, power vent) or forced draft (*i.e.*, power burner of power combustion) systems. An induced draft fan is located downstream of the heat exchanger in the venting system and pulls flue gases through the gas pathway, creating negative pressure in the heat exchanger. A forced draft fan is located upstream of the heat exchanger and creates positive pressure in the heat exchanger that pushes products of combustion through the vent system. Both methods improve efficiency over natural draft systems by providing the correct fuel-to-air ratio to optimize combustion efficiency and by regulating draft to optimize heat transfer in the heat exchanger.

Induced draft combustions systems also have a safety benefit as compared with forced and natural draft systems. Because airflow through the vents is created by inducing a negative pressure in the heat exchanger, air is pulled through the furnace. This suction mechanism ensures that carbon monoxide and other toxic flue gases cannot leak into the heated space in the case of a cracked heat exchanger or venting system.

Induced draft is a baseline feature of non-weatherized gas furnaces and weatherized gas furnaces. Forced draft is a baseline feature of mobile home gas furnaces and non-weatherized oil-fired furnaces.

3.3.2.5 Blower Assembly

The circulating air blower of a residential furnace is typically a centrifugal fan-impeller with a shaft-mounted motor. The assembly with the fan shroud is mounted in an enclosure at the base of an upflow furnace, the return-air end of a horizontal unit, or the top of a downflow furnace.

Air blowers in residential furnaces generally use multi-speed induction motors, typically permanent split capacitor (PSC) designs. Furnaces with premium components may offer electronically commutated (brushless permanent magnet) motors (ECM),[q] which have a higher efficiency and other features, such as modulating capacity controlled by the thermostat.

The blower motor is typically sized for a residential HVAC system based on the quantity of air being moved and the resistance of the system. Because the airflow requirements of central air conditioners are typically higher than those of furnaces, the requirements of the air conditioning system frequently determine the size and electricity consumption of the blower fan motor. However, energy consumed by the blower is not accounted for by the AFUE calculation. DOE is evaluating energy conservation standards for furnace fan electricity consumption in a separate rulemaking procedure.[r]

3.3.2.6 Installation and Venting Options

Non-weatherized furnaces installed within the structure that do not communicate with the heated space (*e.g.*, in a garage, utility closet, or basement) are considered "isolated combustion systems," or ICS. Heat conduction through the furnace jacket dissipates to the unconditioned air around the furnace and is wasted. ICS is the baseline installation for rating and testing of all non-weatherized furnaces, per DOE's test procedure.

The DOE test procedure specifies that all weatherized furnaces shall be rated and tested as outdoor installations. Weatherized furnaces contain an integral venting system that intakes combustion air and exhausts products of combustion to the outside air. Because the combustion system has no communication with the heated space, there are no off-cycle or infiltration losses. The jacket loss from a weatherized furnace, however, is significantly higher than that from an ICS because the unit is exposed to inclement weather such as wind, rain, and snow.

3.3.3 Technology Options That Improve AFUE

DOE identified the following technology options as having the potential to improve the efficiency of furnaces:

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[q] ECM is a trademark of General Electric Company. It is a commonly used industry term; therefore, DOE will use this acronym hereinafter to refer to brushless permanent magnet motors.
[r] See DOE's residential furnace fan webpage for more information, available at www.eere.energy.gov/buildings/appliance_standards/residential/furnace_fans.html

1. Condensing Secondary Heat Exchanger for Non-Weatherized Furnaces
2. Heat Exchanger Improvements for Non-Weatherized Furnaces
3. Condensing and Near-Condensing Technologies for Weatherized Gas Furnaces
4. Two-Stage and Modulating Combustion
5. Pulse Combustion
6. Low NOx Premix Burners
7. Burner derating
8. Insulation Improvements
9. Off-Cycle Dampers
10. Concentric Venting
11. Low-Pressure, Air-Atomized Oil Burner
12. High-Static Oil Burner
13. Delayed-Action Oil Pump Solenoid Valve

DOE considered these technology options further in the screening analysis.

3.3.3.1 Condensing Secondary Heat Exchanger for Non-Weatherized Furnaces

The energy efficiency of gas and oil-fired furnaces can be improved by increasing the fraction of heat extracted from the combustion gases such that the water vapor begins to condense. Condensation of the vapor in the flue gases signals an efficient transfer of energy from combustion gases to circulation air and is usually achieved by the addition of a secondary heat exchanger. The secondary heat exchanger, which is typically a tube-fin type heat exchanger constructed from corrosion-resistant stainless steel, allows more heat to be extracted from the flue gases before the products of combustion exit through the flue to the vent system.

Flue gas condensate is acidic and corrosive. Corrosion due to condensation of combustion gases limits the AFUE that can be achieved by a non-condensing furnace to ratings below 82 percent AFUE. Using corrosion-resistant heat exchangers and lining the vent system with corrosion-resistant material allows for AFUE improvements while reducing the risk of corrosion damage to the heat exchanger and venting system.

3.3.3.2 Heat Exchanger Improvements for Non-Weatherized Furnaces

Improving the heat exchanger for furnaces can increase the rate of heat transfer from the hot combustion gases to the circulation air that is distributed to the heated space. The improved heat transfer increases thermal efficiency and AFUE.

Improvements to the heat exchanger can be achieved by modifying baseline designs of standard furnaces to incorporate any combination of (1) increased heat exchanger surface area, (2) heat exchanger surface features, and (3) heat exchanger baffles and turbulators.

Increased Heat Exchanger Surface Area. The performance of the heat exchanger can be improved by increasing surface area. An increase in surface area provides a larger surface over which heat transfer can occur. This increases the overall rate of heat transfer occurring in the furnace, thereby improving the furnace's ability to efficiently extract heat from the hot combustion gases. The result is an increase in the steady-state efficiency of the unit, and thus, the AFUE.

Generally, manufacturers increase the surface area of the heat exchanger by increasing the size of the secondary heat exchanger. If the gas temperature is too low, the gases will begin to condense inside the primary heat exchanger, which is usually not corrosion-resistant. Areas where condensation occurs in the primary heat exchanger are known in the industry as "cold spots" and are detrimental to the integrity of the heat exchanger. Manufacturers thus limit the surface area of the primary heat exchanger in order to avoid the formation of cold spots and instead increase surface area in the corrosion-resistant secondary heat exchanger.

Heat Exchanger Surface Features. An alternative to increasing the size of the heat exchanger is enhancing the effectiveness of the heat exchanger surfaces. One way this may be done is by adding surface features to the heat exchanger. Incorporating surface features, such as dimples, increases turbulence in the air passing close to the heat exchanger's surface, which can enhance heat transfer when correctly designed.

Heat Exchanger Baffles and Turbulators. Turbulators and baffles are pieces of metal that are incorporated into the heat exchanger to improve heat transfer through the walls of the heat exchanger. Turbulators, which are common in gas furnaces, are typically very thin, twisted strips of stainless steel inserted longitudinally into the tubes of the secondary heat exchanger, parallel to air flow. They improve heat transfer by restricting flow in the heat exchanger tubes, increasing turbulence in the combustion gases. Baffles, frequently used in oil-fired furnaces, are simply fins or extrusions from the combustion-air side of the heat exchanger wall. Baffles enhance heat transfer primarily by deflecting the products of combustion toward the heat exchanger wall.

3.3.3.3 Condensing and Near-Condensing Technologies for Weatherized Gas Furnaces

In weatherized furnaces, which are installed outdoors and therefore exposed to winter weather conditions, the liquid condensate could freeze in the drain and disrupt proper operation. Manufacturers have not succeeded in developing a weatherized furnace that can prevent condensate from freezing.

3.3.3.4 Two-Stage and Modulating Combustion

Two-stage and modulating combustion allows furnaces to meet heating load requirements more precisely. When low heating load conditions exist, a two-stage or modulating furnace can operate at a reduced input rate for an extended period of burner on-time to meet the reduced heating load. This improves comfort by reducing large fluctuations in room temperature. Because burner on-time increases, however, fuel use does not decrease; and with combustion air supply held constant, there is minimal effect on AFUE.[63] When the combustion air supply is modulated to match the fuel input rate, however, the burner is essentially derated, making the heat exchanger more effective during periods of lower heat demand and significantly raising AFUE. Two-stage and modulating combustion is common in gas furnaces and is an emerging technology in oil-fired furnaces.

Two-Stage and Modulating Gas Burners. Two-stage and modulating gas burners reduce cycling of the furnace by reducing the flow rate of gas at lower heating loads. These burners regulate gas flow but not airflow. When a modulating or two-stage burner is paired with a single-stage combustion fan, a greater percentage of excess air is induced at the lower gas flow rate, resulting in lower combustion efficiencies when compared to the normal or maximum gas flow rate. Because of this, furnaces equipped with two-stage or modulating burners but without two-stage or modulating combustion fans will always have lower energy efficiency, as measured by the DOE test procedure, than furnaces equipped with single-stage burners.

To overcome this lower efficiency and achieve efficient two-stage or modulating combustion, an induced draft or forced draft system using a two-speed or variable speed combustion fan must be paired with the two-stage or modulating burner. With the multi-speed combustion fan, the excess air drawn into the burner at low gas flow rates can be reduced in order to improve the steady-state efficiency of the furnace.

Two-Stage and Modulating Oil Burners. Oil burners are typically oversized such that the design load is rarely met. Because oil-fired furnaces usually operate at part load, oil-fired furnaces suffer from significant stack losses and standby heat losses. To address poor field performance, two-stage and modulating oil burners have recently emerged on the oil-fired furnace market. Unlike their gas counterparts, oil burners are equipped with integrated combustion fans; and as such they do not need to be paired with an additional fan to achieve efficient reduced-rate operation. These advanced burners use smart controls to detect the heating load and determine low- or high-firing rates. In most cases, the reduced firing rate is sufficient to meet the heating load. Two-stage and modulating oil burners with two-stage and modulating combustion fans meet part-load demand with less excess heat lost through the flue, and therefore operate more efficiently, than single-stage oil burners. An initial calculation indicated that two-stage and modulating combustion can increase AFUE by 5 percent when used in a residential oil-fired furnace.[64]

3.3.3.5 Pulse Combustion

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber (drawing a fresh fuel-air mixture into the chamber) and pressurize it (causing ignition by compression heating of the mixture to its flash point). This process is initiated by a blower that supplies an initial fuel and air mixture to the combustion chamber. A spark ignites the mixture. Once resonance is initiated, the process becomes self-sustaining. Pulse frequencies are on the order of 60 to 70 cycles per second.[65] The turbulent nature of the pulse combustion process requires no mechanical devices (*e.g.,* induced draft fans or power burners) to vent the combustion products to the outside.

Pulse combustion systems feature high heat transfer rates, can self-vent, and can operate as isolated combustion systems. Because the pulse combustion process is highly efficient, the burners are generally used with condensing appliances.

In contrast to furnaces that utilize natural draft and induced draft technologies, pulse combustion furnaces generate positive pressure in the heat exchanger. This creates a potential safety problem because any breach in the heat exchanger would result in a leak of toxic combustion products into the circulation air stream.

Pulse combustion gas furnaces were available in the United States for more than two decades, but they were withdrawn from the market because the manufacturers found that competing technologies such as condensing secondary heat exchangers cost significantly less to manufacture and operate. There are currently no pulse combustion furnaces available on the market.

3.3.3.6 Low NOx Premix Burners

Low NOx premix burners reduce emissions in two ways: by reducing peak flame temperature and by reducing levels of excess air. They achieve this by completely premixing the primary air and fuel prior to combustion, thereby eliminating the need for secondary air. The greater level of primary air in the lean, premixed air-fuel mixture creates a uniform flame shape that ensures oxygen availability to all regions of the flame. This eliminates the interior region of an inshot burner flame, where sub-stoichiometric, fuel-rich "hot spots" form "thermal NOx" at a rate that increases exponentially with flame temperatures above 2,800 °F. In addition, the absence of secondary air reduces the amount of free oxygen and nitrogen available to the flame exterior, thereby reducing "prompt NOx formation." Aside from NOx reductions, the leaner, premixed flames also have a higher overall flame temperature than flames with secondary air. The hotter, leaner, premixed flame improves heat transfer and AFUE. It also raises the water vapor dew point, which facilitates condensation and further improves AFUE in condensing mode. The use of low NOx premix burners in a residential furnace would require a major redesign. As such, low NOx burners have not yet been successfully incorporated into a residential furnace design.

3.3.3.7 Burner Derating

Reducing burner firing rate for gas and oil furnaces while keeping heat exchanger geometry and surface area the same will increase the ratio of heat transfer surface area to energy input, thereby increasing the annual fuel utilization efficiency. However, the lower energy input means that less heat, and thus lower utility, would be provided than with conventional burner firing rates.

3.3.3.8 Insulation Improvements

The DOE test procedure requires that all non-weatherized furnaces shall be rated as isolated combustion systems and all weatherized furnaces shall be rated as outdoor installations. The test procedure specifies that the jacket loss for units intended for installation outdoors or in an unheated space may either be assigned a fixed value of 1% of the hourly input rating or a jacket loss measurement may be performed. If the jacket loss test is performed, insulation improvements may realize AFUE gains; therefore, DOE considered increasing or improving the insulation of a furnace.

Insulation can be improved by modifying the baseline furnace design through the use of increased jacket insulation or advanced forms of insulation.

Increased Jacket Insulation. Manufacturers insulate furnaces by adding insulation to the inside wall of the cabinet. Most residential furnaces on the market today, including weatherized furnaces, have ½-inch thick fiberglass insulation. Increasing the thickness of the jacket insulation could reduce standby losses by reducing heat loss through the jacket. Jacket losses represent a majority of the standby losses. Some manufacturers produce furnaces with increased insulation.

Advanced Forms of Insulation. Alternate ways of reducing the jacket losses without increasing the footprint of furnaces include using advanced insulation materials or evacuated panels. Some of the advanced materials or methods of insulation considered here involve using foam insulation, vacuum insulation, inert gases, aerogel insulation, or partial vacuums.

Foam Insulation. Foam insulation can be used as an alternative to fiberglass insulation. Chlorofluorocarbon-free, water-blown polyurethane foam is a common alternative to high-density fiberglass blankets. Incorporating foam insulation of the same thickness in place of fiberglass insulation can increase the overall efficiency of a furnace. Foam typically has an R-value up to two to three times greater than fiberglass. Additionally, foam can be blown into small spaces and constrictive geometries where the potential for heat loss still exists, and which would be difficult to fill with fiberglass batts. Finally, manufacturing processes that use foam-blowing techniques are better suited for production line changes due to the shape-conforming characteristics of the foam. This allows additional technology options, methods, and advances to be incorporated into current designs with minimal impacts on insulation installation techniques.

Vacuum Insulation Panels (VIP). A "hard" vacuum between internal reflective surfaces is a very good insulator. It has been used for years in Thermos bottles and Dewar tanks for cryogenic applications. Durability and the difficulty of maintaining the seal over the life of the furnace are some of the manufacturing problems that remain unresolved. This technology has not been demonstrated for use with furnaces.

Gas-Filled Panels (GFP). Gas-filled panels are thermal insulating devices that retain a high concentration of a low-conductivity gas at atmospheric pressure within a multilayer infrared reflective baffle. The thermal performance of the panels depends on the type of gas fill and the baffle configuration. Gas-filled panels are flexible and self-supporting and can be made in a variety of shapes and sizes to thoroughly fill most types of cavities. This technology has not been demonstrated for furnace applications.[66]

Aerogel Insulation. Silica aerogel, an advanced insulation material, is composed of 96 percent air and 4 percent silicon dioxide. Aerogels are more efficient and weigh less than the fiberglass insulation currently used in most furnaces. The R-value of the aerogel at atmospheric pressure is comparable to that of polyurethane foam, but when 90 percent of the air is evacuated from a plastic-sealed aerogel packet, its resistance nearly triples. New manufacturing processes have been developed that can produce flexible blankets or clamshell forms of this material. The aerogel material is vulnerable to shock and vibration; however, material handling is an issue. Because the aerogel is hygroscopic, it requires a thorough sealing of the cavity between the heat exchanger and the cabinet. The material has not been demonstrated for use with furnaces.

Evacuated Panels. Other materials with a lightweight open structure can provide effective insulation combined with "soft" or low vacuums. The materials can be enclosed with metals or plastic. A vacuum is drawn in this panel before sealing, and lightweight, rigid foam keeps the vacuum from compressing the panel. This technology has not been demonstrated for furnaces.

3.3.3.9 Off-Cycle Dampers

Off-cycle (which refers to the burner off-cycle) dampers restrict the intake and exhaust air flow through the venting system during standby mode by closing when the burner is not operating, thereby trapping residual heat in the heat exchanger. During the burner off-cycle, the furnace loses heat by natural convection and conduction through the combustion air inlet and flue. Installing a damper at these points can prevent heat from escaping and minimize off-cycle heat losses.

Dampers have no effect on the steady-state performance of the furnace; however, they can reduce standby losses. The AFUE metric captures both steady-state and standby performance of the furnace, and thus any heated air that is retained in the system during the standby mode improves the system's annual fuel utilization efficiency.

The safety standard for gas-fired central furnaces, ANSI/AGA Z21.10.1-1993: "Gas-Fired Central Furnaces," requires the burner to shut off if the flue gets blocked. [67] Thus, the effects of a failure of the flue damper to open should be mitigated by the burner controls.

Electro-Mechanical Flue Damper. A damper that is installed downstream of the heat exchanger is called a flue damper. Electro-mechanical flue dampers are activated by an external source of electricity. These dampers open when combustion starts and close immediately after combustion stops. When the damper reaches the open position, an interlock switch energizes the solenoid and enables the gas ignition circuit. Therefore, as a safety measure, the burner cannot be ignited when the damper is in the closed position. Because the dampers open and close immediately, no bypass is needed. The electro-mechanical flue damper needs an electrical connection and consumes a nominal amount of power during opening and closing.

Electro-Mechanical Burner Inlet Damper. Inlet dampers are installed at the combustion-air inlet to the burner box and are designed to automatically close off the air passage and restrict the airflow through the heat exchanger when the burner is off. The principles and means of operation of an electro-mechanical inlet damper are identical to those of an electro-mechanical flue damper.

3.3.3.10 Concentric Venting

Furnaces using outdoor combustion air may use a combustion air preheat venting system that passes the outdoor combustion air through a heat exchanger in contact with the flue gases. The combustion air does not mix with the flue gases. Manufacturers accomplish this preheat design by running the inlet and exhaust vents concentrically. The flue gases are exhausted through a central vent pipe and the intake combustion air passes through a concentric duct surrounding it. This arrangement creates a counter-flow heat exchanger that recovers some heat from the flue gases to preheat the combustion air.

Concentric venting provides an efficiency advantage compared to conventional venting systems, as the concentric vent essentially serves as a shell-in-tube heat exchanger. Some furnace manufacturers report separate AFUE ratings for each model with both concentric and conventional venting. In such cases, models tested with concentric venting always show an efficiency enhancement of a few tenths of a percent AFUE over those with conventional venting configurations.

3.3.3.11 Low-Pressure, Air-Atomized Oil Burner

The residential oil burner market is currently dominated by the pressure-atomized retention head burner. This type of burner delivers oil to the fuel nozzle at pressures of 100 to 150 pounds per square inch and is generally available at firing rates of more than 70,000 Btu/h. The fuel input rate is controlled by the size of the nozzle orifice. Pressure-atomizing nozzles that are designed for low firing rates suffer rapid fouling of the small internal passages, leading to bad spray patterns and poor combustion performance.

To overcome the low input limitations of conventional oil burners, Brookhaven National Laboratory developed a low-pressure, air-atomized oil burner that can operate at firing rates as low as 0.25 gallons of oil per hour (10 kW). In addition, it can operate with low levels of excess combustion air (less than 10 percent) for lean-burning, ultra-clean combustion. A lower level of excess air generally improves AFUE rating. This single-stage burner design is also capable of firing fuel at high and low input rates, which are manually actuated by a switch, allowing it to closely match the smaller heating loads of well-insulated modern homes. The ability to derate the flame also greatly enhances the effectiveness of the heat exchanger, which improves steady state efficiency.

3.3.3.12 High-Static Oil Burner

A modification of the conventional flame retention head burner is the high-static pressure flame retention head oil burner. These burners employ an air guide to direct air onto the optimal point on the blower wheel and a scroll insert to create high static pressure in the combustion chamber while maintaining consistent air flow. This higher pressure enables the furnace to overcome restrictive flow passages in compact, more efficient, heat exchangers.[68] These types of burners are also able to operate at lower levels of excess air, giving them a nearly 5 percent AFUE advantage over flame retention head burners.[69,70]

3.3.3.13 Delayed-Action Oil Pump Solenoid Valve

A delayed-action oil pump solenoid valve is installed between the oil pump and the burner nozzle to supplement the fuel pump regulator by delaying the fuel release by three to six seconds after the igniter and burner blower start until the oil pressure reaches the level required to fully discharge the oil into the combustion chamber without dripping. This ensures that the oil burns more completely.[71] Testing at Brookhaven National Laboratory indicates that the typical efficiency benefit of delayed-action solenoid valves is expected to be less than 1 percent AFUE.

3.3.4 Technologies Options That Do Not Improve AFUE

DOE preliminarily determined that the following technology options do not improve the fuel efficiency of furnaces:

1. Infrared Burner
2. Improved Blower Efficiency
3. Micro Combined Heat and Power (Micro-CHP)
4. Positive Shut-Off Valve for Oil Burner Nozzles

These technologies were not carried forward to the screening analysis.

3.3.4.1 Infrared Burner

Infrared (IR) burners are typically premix burners that produce a high radiant heat flux with low NOx emissions. The primary mechanism of heat transfer in infrared burners is radiation, in which heat is emitted in the form of a wave. The infrared waves emitted by the burner are transmitted at the speed of light in a straight line without heating the air. When the waves strike an opaque object, they are absorbed and converted back to heat. The heated object can then dissipate its heat via conduction or convection.

Infrared burners have higher combustion efficiencies than traditional gas inshot burners. Gas and primary air flow through the porous material or fiber mesh of the burner without need for secondary air. Because they are able to operate at lower levels of excess air, infrared burners have a small combustion efficiency advantage over traditional blue-flame burners.

Several infrared burner materials have been developed, including ceramic, stainless steel, and glass fiber. Most ceramic burners are flat plates, which have not been used in residential gas furnaces. Several ceramic burner designs consisting of ceramic fibers formed into a mat structure have been manufactured.[72] This design satisfies the heating load requirements for residential furnaces, has very low NOx emissions, and is capable of operating within a very wide turndown ratio (the ratio of the maximum to minimum output). However, it has not been incorporated and demonstrated in a working residential furnace prototype. Another burner design incorporates perforated high-temperature stainless steel and woven high-temperature wire. These burners are formable and adaptable to various configurations; however, they are not very durable because the metal gets brittle with time, creeps out of shape, and cracks. Glass fiber is the most successful material because it can be formed and will reliably maintain its shape.

Infrared burners made out of these materials are commonly used in industrial processing furnaces, room heaters, cooktop appliances, and other applications that require direct heating of an object. The application of IR burners to a residential furnace would require a major redesign of the heat exchanger to take advantage of radiative heat transfer from the burner. To DOE's knowledge, IR burners have not been incorporated into a warm-air furnace design; and as such, it has not been demonstrated that IR burners can improve overall system efficiency.

3.3.4.2 Improved Blower Efficiency

All furnaces come equipped with blower fans to circulate the heated air over the heat exchanger and through the plenum for distribution to the conditioned space. The efficiency of the air circulating blower can be increased by improving the blower motor efficiency and/or blower impeller efficiency to reduce the electrical energy consumption of the unit. However, electrical energy consumption of the furnace fan does not affect AFUE and therefore is not covered by this rulemaking.

3.3.4.3 Micro Combined Heat and Power (Micro-CHP)

It is possible to use the heat generated by a furnace's combustion system to generate electricity opportunistically.[73, 74] Self-generated electricity can be used to operate the electrical components of the furnace or can be sold back to the grid. Known methods of micro-CHP include fuel cell generators, thermophotovoltaic (TPV) generators, thermoelectric generators, and thermionic conversion. Other techniques use engines based on the Rankine cycle, Brayton cycle, Stirling cycle, or Otto cycle, where the engine drives an electrical generator or provides direct mechanical power and the waste heat from the engine is used for space heating. Neither the furnace's electricity use nor the heat generated by its electrical components, however, contribute to the calculation of its seasonal efficiency. Therefore, this technology option will have no effect on AFUE.

3.3.4.4 Positive Shut-Off Valve for Oil Burner Nozzles

One option for oil-fired furnaces is a positive shut-off valve on the fuel nozzle, which reduces smoke and soot production during burner start-up and shutdown.[75] This valve is generally installed directly in the nozzle tip and prevents oil from dripping into the combustion chamber. This option can also be retrofitted on existing burners. A positive shut-off valve in an oil burner nozzle does not affect the efficiency of the appliance, but plays a role as an emission-control device.

3.4 CENTRAL AIR CONDITIONER AND HEAT PUMP TECHNOLOGY ASSESSMENT

The purpose of the technology assessment is to develop a preliminary list of technologies that could potentially be used to improve the efficiency of central air conditioners and heat pumps. The following assessment provides descriptions of technologies and designs that apply to subsystems within all product classes of central air conditioners and heat pumps, as well as innovations that apply to heat pumps only.

3.4.1 Compressor Improvements

Several technologies exist to increase the efficiency of the compressors used in central air conditioner and heat pump systems. High efficiency reciprocating and scroll compressors, sometimes incorporating variable-speed motors, all have higher efficiencies than the traditional reciprocating compressors commonly used in air conditioners.

Scroll compressors compress gas in a fundamentally different manner from traditional compressors—between two spirals, one fixed and one rotating. High efficiency reciprocating compressors are as efficient, or more efficient, than scroll compressors. However, these compressors are often considered to present some drawbacks exist including noise, cost, and reliability, compared to scroll compressors.

Variable-speed compressors are implemented through the use of an electronic control on the compressor motor, which allows the motor to operate at different speeds. This feature typically increases efficiency over a broad operating range but does not inherently increase maximum efficiency at the compressor rating point. Variable-speed compressors reduce energy consumption in several ways:

1. When refrigerant flow is reduced during part-load operation, the condenser and evaporator (designed for full flow conditions) are more effective and thus more efficient.

2. Close matching of load eliminates the cycling that occurs with single-stage compressors, and cyclic losses penalize SEER and HSPF ratings. During the off-cycle, the pressure in the system equilibrates. At the intermediate pressure, refrigerant vapor will condense in the cold evaporator rather than the condenser. Essentially, some of the heat rejection load is rejected to the evaporator during this time, reducing overall system performance. Variable speed operation would eliminate or significantly reduce compressor off-time and the related inefficiencies.

3. Reduced pressure rise across the compressor at lower capacity also improves efficiency by requiring less pumping power. Maintaining a constant pressure is more efficient because losses at higher pressure rise are greater than gains at lower pressure rise.

3.4.2 Fan System Improvements

3.4.2.1 Higher Efficiency Fan Motors

Fan motors are fractional horsepower in size, are responsible for moving air across the indoor and outdoor coils, and typically run at one speed. The manufacturer will match the motor size and fan blade to the coil to meet the expected cooling load under most conditions. Higher efficiency fan motors reduce energy consumption by requiring less electrical power to generate motor shaft output power.

Electric motors operate based on the interaction between a field magnet and a magnetic rotor. In a brushed motor, the field magnets are permanent magnets and the rotor is an electromagnet; the situation is reversed in a brushless motor. The electromagnetic interactions between these two magnets cause the rotor to rotate.

Nearly all fan motors for standard central air conditioners and heat pumps are of the permanent split capacitor (PSC) variety. In PSC motors, the electromagnet consists of windings of electrical wire through which current is driven. Through electromagnetic induction, this magnetic field induces current in the conductor bars of the rotor. The conductor bars of the rotor, often made of copper or aluminum, are arranged in such a manner that they produce another magnetic field once current is induced. The interaction of the magnetic field of the electromagnet and the magnetic field of the rotor results in rotation of the rotor. A smaller, start-up winding is present in addition to the main winding. The start-up winding is electrically connected in parallel with the main winding and in series with a capacitor. At start up, the interactions between the magnetic field generated by the start up winding and that generated by the main winding induce rotation. Because of the capacitor, however, the current to the start-up winding is cut off as the motor reaches steady state. PSC motors are produced in large quantities and are relatively inexpensive with motor efficiencies ranging from 50 to 70 percent.

Electronically commutated motors (ECM) are brushless permanent magnet motors with motor efficiencies between 70 and 80 percent, making them more energy efficient than PSC motors. Like a PSC motor, the stator of an ECM is an electromagnet used to produce a magnetic field. Unlike the PSC motor, the rotor of an ECM consists of a permanent magnet. The interaction of the magnetic field of the electromagnet and the magnetic field of the permanent magnet rotor result in rotation of the rotor. ECMs generally operate more efficiently than PSC motors. While PSC motors operate most efficiently at a single speed with significantly diminishing operating efficiency at others, ECMs are capable of maintaining a high operating efficiency at multiple speeds. However, ECMs can weigh twice as much as equivalent PSC motors. In addition, ECMs are complex, and can be significantly more expensive than PSC motors.

A way to further improve the efficiency of motors used for central air conditioner and heat pump applications is to make the critical components of an induction motor's rotor (e.g., conductor bars and end rings) out of copper instead of aluminum. Due to difficulties with casting copper, making these components out of aluminum is the common current practice. However, the greater conductivity of copper results in lower resistance heating losses in the rotor, and thus lower losses in the motor when compared to traditional aluminum motor parts. Recently, the creation of copper dies made from special alloys has allowed for the advancement of copper casting techniques. Additional improvements in the design and fabrication of copper motors, such as optimization of the steel laminations, could further increase the efficiency of copper motors over aluminum motors.

3.4.2.2 Higher Efficiency Fan Blades

High efficiency fan blades move air more efficiently, yielding energy consumption savings by reducing the required fan shaft power. The fans typically used in central air conditioners and heat pumps have stamped, curved sheet metal blades. The blades are typically supplied by a fan blade manufacturer and mounted to the motor by the manufacturer. Consequently, they are not likely to be optimized for the particular central air conditioner or heat pump that they are installed on. Fans may have lower efficiencies due to the higher required pressure drops, for which sheet metal fans are not well suited. Required fan shaft power could be reduced if the fan blades were optimized for each given application.

3.4.3 Expansion Valve Improvements

Expansion valves are refrigerant metering devices whose purpose is to control the amount of refrigerant flowing to the evaporator coil. In doing so, they simultaneously decrease the temperature and pressure of the refrigerant, creating a cold liquid-vapor mixture. The low temperature of the refrigerant leaving the expansion valve creates the driving force to move heat out of the refrigerated space and into the evaporator.

The most basic type of expansion device is a capillary tube, which may be found in older, less efficient air conditioners and heat pumps. The capillary tube is a long, thin piece of pipe that creates a pressure drop in the refrigerant through frictional losses. Capillary tubes must be sized to the particular application and cannot adjust for variations in load or ambient operating conditions. They are often oversized for worst-case conditions, and therefore may operate at reduced efficiency during normal operation.

The thermostatic expansion valve (TXV) is common in air conditioners and heat pumps rated at an efficiency level of 13 SEER or above. This device uses an orifice to reduce the pressure of the entering refrigerant and a sensing bulb to monitor and maintain the temperature of the superheated vapor leaving the evaporator. Because the TXV allows for some degree of adjustment of refrigerant expansion, it may be somewhat more efficient than the capillary tube device under varying conditions.

The electronic expansion valve (EEV) is similar to the TXV, but uses an electronic control system to optimize refrigeration-system performance under all operating conditions. Because it does this with greater flexibility than that allowed by a TXV, an EEV theoretically allows for further increases in energy efficiency under varying conditions when paired with advanced modulating systems.

3.4.4 Heat Exchanger Technologies and Improvements

3.4.4.1 Baseline Technology

Most residential central air conditioners and heat pumps currently on the market utilize traditional tube-and-fin heat exchangers for both the evaporator and condenser coils. These coils are refrigerant-to-air heat exchangers composed of metals with high thermal conductivity, usually aluminum and copper, with the tubes generally being composed of copper and the fins of aluminum.

The evaporator coil is responsible for evaporating and superheating the entering refrigerant liquid-vapor mixture while extracting heat from the air in the conditioned space. The internal heat-exchanging surfaces in contact with refrigerant are commonly referred to as "refrigerant-side" while the external heat-exchanging surfaces in contact with the air are referred to as "air-side." Because a temperature difference is necessary to drive heat from the air into the refrigerant, the saturated evaporator temperature must be considerably colder than the evaporator's discharge air temperature. The magnitude of this driving force is directly related to the total cooling load and the thermal characteristics of the evaporator.

The condenser coil is responsible for condensing and sub-cooling the entering refrigerant vapor while rejecting heat from the refrigerant to the ambient air.

The majority of evaporator and condenser coils used in central air conditioners and heat pumps currently on the market are of the traditional tube-and-fin heat exchanger design. Many manufacturers utilize a similar process in building coils, and this methodology has remained fundamentally the same over the long period during which these products have been in use. The actual techniques utilized in this process vary by company, and proprietary methods are often utilized by specific manufacturers in the production of coils. Manufacturing of coils in-house is a process which requires high capital investments in machinery and line setup. As a result, manufacturers have been hesitant to move away from the traditional method of coil production, as doing so would require large new investments. Instead, companies have historically focused on improving the performance of their existing coil designs.

3.4.4.2 Improvements to Baseline Coils

Increasing the overall size of the coil in one or more dimensions tends to be the most cost-effective way to increase the system efficiency. Increasing the area of the evaporator coil decreases the necessary temperature difference and therefore decreases the required saturated evaporator temperature. Increasing the area of the condenser coil decreases the necessary change in temperature across the coil. Both result in increased compressor efficiency (increased EER and reduced energy consumption). However, many applications limit the amount of coil size increase in order to maintain overall cabinet dimensions. Most approaches to increasing the coil surface area also result in an increase in required fan motor power and an increase in refrigerant pressure drop. Enhancements to the refrigerant-side surface area of both evaporator and condenser coils typically include rifled or diamond-pattern tubing and increased number of tube passes. Enhancements to the air side surface area include increased fin pitch (decreased fin spacing), fin patterns (wavy or zig-zag), and increased numbers of tube passes. The size constraints facing manufacturers who have already maximized the size of their units make it necessary for these companies to consider alternative methods to improving heat exchanger performance.

3.4.4.3 Alternative Coil Technologies

Liquid Suction Heat Exchangers. The function of a liquid suction heat exchanger is to further cool the flow of liquid refrigerant entering the expansion valve using the flow of gaseous refrigerant leaving the evaporator, thus providing sub-cooling for the entering liquid by super-heating the exiting suction vapor. Hotter suction vapor is less susceptible to heat gains in the return piping to the compressor rack. The compressor work is increased, however, because the suction vapor has greater enthalpy. In addition, the possibility of compressor overheating problems, brought on by the combination of increased compressor work and hotter vapor, limits the use of this method in some situations. The possibility for these problems and the potential gains of liquid suction heat exchangers depend on the several factors, including evaporator temperature, type of refrigerant used, and system pressures. These potential issues indicate that the performance of an LSHX is dependent upon a number of factors, including refrigerant type, operating temperature, and ambient conditions, and thus DOE does not have enough information to suggest that an LSHX would consistently increase SEER or HSPF as rated using the DOE test procedure. Consequently, DOE did not consider LSHXs as a design option in the engineering analysis.

Microchannel Heat Exchangers. Several companies produce microchannel heat exchangers, which are mainly used in the automobile industry. Unlike a conventional round-tube plate-fin heat exchanger, the microchannel has a rectangular cross-section containing several small channels through which refrigerant passes. Fins pass between the tubes and are brazed to the tubes, and all components are aluminum. The resulting microchannel coil transfers more heat per unit of face area than does a round-tube plate-fin coil of comparable capacity. It does so with a lower airside pressure drop, yielding reduced fan power consumption. These benefits can improve system EER and SEER ratings in residential air conditioners when compared to a condenser coil of the same face area. This would allow manufacturers to improve the rated SEER without further increasing the size of the units.

Although the microchannel heat exchanger costs more to produce than a conventional round-tube plate-fin coil, this product offers particular opportunities to reduce the size and weight of the heat exchanger. Those advantages led to the rapid and almost total transition of the automobile air conditioner market to microchannel technology. Microchannel heat exchangers also offer significant reductions in refrigerant charge, which suggests that they may reduce the rate of compressor failures caused by refrigerant slugging.

Even after several years of dominance in the automobile market, the microchannel heat exchanger has not penetrated the building air conditioning markets where size and weight constraints are not as important. The cost advantages of reducing the size and weight of the condenser or the capacity of the system have not sufficiently outweighed the added costs and risk associated with the microchannel technology for these systems to attain widespread use in building applications to date. Additionally, given the fact that most manufacturers produce coils in-house, and that setting up a coil production line is an extremely capital-intensive process, manufacturers are generally hesitant to make the large investments needed to move away from the production of traditional tube-and-fin heat exchangers. Moreover, several limitations and uncertainties are particularly hindering the large-scale adoption of microchannel heat exchangers. First, microchannel construction makes condensate removal much more challenging than traditional tube-and-fin heat exchangers. This poses a serious barrier to the adoption of the technology in evaporators and in heat pump condensers. Some manufacturers may decide not to adopt the new technology if they cannot offer it in all of their products, including both air conditioners and heat pumps. Second, there are concerns whether residential microchannel heat exchangers are proven to perform well under wide variations in ambient temperatures given that they are considerably larger than automobile heat exchangers and are configured differently. Third, compressor lubrication is entrained in the refrigerant, and residential microchannel heat exchangers must display a proven ability to consistently return lubricant to the compressor to avoid costly damage. Fourth, manufacturers are concerned that contractors will not be able to repair coil leaks effectively because of the difficulty of successfully brazing aluminum in the field.

Flat-Tube Heat Exchangers. Flat-tube, louver-fin heat exchangers offer various advantages over traditional round-tube, plain-fin heat exchangers. The flat-tube design reduces wake region, which decreases heat transfer downstream of round tubes. The design improves fin efficiency and creates a lower profile drag as a result of the smaller tube projected area. Serpentine louvered-fin, flat-tube heat exchangers have already been utilized in automotive applications because of their ability to produce the same amount of heat transfer with much more compact designs than the plain-fin, round-tube variety heat exchangers. In laboratory tests, the louver-fin, flat-tube heat exchanger was found to produce heat transfer coefficients that were 90% higher than those produced by a plain-fin, round-tube heat exchanger[76]. The significant increase in heat transfer coefficient resulted in a size reduction factor of two to three for a residential absorption heat pump system. The more efficient flat-tube heat exchangers would be able to provide the same amount of heat transfer and reduce the amount of airflow needed from the fans, thus reducing the amount of electricity consumed by the fan motors and increasing system efficiency.

Like the microchannel technology, the flat-tube heat exchangers still have not broken through into the air conditioner and heat pump market, where the size of the unit is not as much of a concern. The extra cost of developing these systems and investing the large amounts of capital needed to produce them in-house has not yet been offset by the potential advantages to using flat-tube heat exchangers. Also, condensate removal is a concern in louvered-fin, flat-tube heat exchangers because of water "bridges" that get into the louver gaps and reduce heat transfer.

3.4.5 Inverter Technology

Inverter technology can improve air conditioner and heat pumps efficiency through more efficient control of the fan motors and compressor. The incoming AC current is converted to DC current by a rectifier and then back to AC current at a specific frequency by an inverter. This AC current is used to drive the motor or compressor, whose speed is calibrated to the frequency of the AC current. Though there are other ways to change motor speed, inverter technology allows for standard AC fans motors and compressors to maintain efficiency at variable speeds. The ability to vary capacity as needed allows for inverter driven components to avoid cycling on and off as much as non-inverter driven components. This reduces the fluctuations in temperature of the conditioned space and also helps to extend component lifetime.

In terms of SEER and HSPF, the benefits of inverter technology are seen through more efficient operation of the motors and compressor. Reduction of a unit's power draw during the applicable tests increases either the SEER or HSPF rating produced by the test. Because inverter driven compressors and fan motors can operate at partial loads, manufacturers are more likely to conduct the optional cyclic C and D tests to determine the degradation coefficient (C_d) instead of using the default value of 0.25.

3.4.6 Designs Relevant Only to Heat Pumps

The following technologies, defrost mechanisms and defrost cycle control, are two examples of defrost-related improvements applicable to heat pump designs. They are not intended to comprise an exhaustive list of viable technologies.

3.4.6.1 Defrost Mechanisms

As the outside air passes over the outdoor coil of a heat pump operating in heating mode, its heat is absorbed by the refrigerant inside the coil, which lowers the temperature of the ambient air. When the temperature of the surrounding air is reduced to less than 32°F, the moisture in the air will condense and freeze on the outdoor coil, forming a layer of frost. The frost reduces performance by increasing the thermal resistance to heat transfer from the coil to the air and by obstructing airflow. Both the method in which defrost is performed and control of the defrost cycle can lead to increased energy savings.

The standard method of defrosting the outdoor coil during the heating operation of a heat pump is to temporarily reverse the flow of the refrigerant. This will use some of the heat from air inside to heat the outdoor coil and melt the frost. At the same time the indoor coil is cooled, and it becomes necessary to heat the house using an auxiliary heating system (typically electric resistant heaters).

"Frost-less" heat pump defrost technology slows frost accumulation on the outdoor coil while also increasing the heating capacity by adding an accumulator to the heat pump cycle. The accumulator traps heat from the condensed liquid from the condenser, and this causes an increase the suction pressure of the compressor. This addition of heat to the accumulator increases the outdoor coil temperature by several degrees and thus reduces the frost accumulation on the coil. Also, much of the heat added to the accumulator is still brought inside by increased heat pump supply air temperature since the suction pressure of the compressor was increased. The frostless heat pump still may accumulate frost, however, if the heat pump is operated for a long period of time at low ambient temperatures, creating the need for a cycle reversal for defrosting. During the reverse cycle, the indoor blower is shut off and the refrigerant flows to the accumulator, making the accumulator take over the function of the evaporator. This allows for reverse cycle to defrost while also preventing cool air from being blown inside and reduces the need for resistance heaters. When the surrounding temperature drops below 32°F, increasing the temperature of the outdoor coil a few degrees will not prevent frost accumulation, and heat input to the accumulator becomes useless. Therefore, the accumulator should only be used at temperatures between 32°F and 41°F, when frost is most likely to collect on the coil and the use of the accumulator will be able to reduce the amount of frost. Therefore, this technology is only effective within a small range of ambient temperatures at and above the freezing point of water. Additionally, such systems increase compressor work and thus do not appear to have any positive benefit on rated SEER or HSPF values as measured using the DOE test procedure.

Another mechanism for reducing the number and duration of defrost cycles is hot water-source defrosting. In heat pumps equipped with hot water defrost, a specifically designed system of valves and conduits allow the heat pump to selectively send the refrigerant to the various heat pump components, depending on which heat pump functions are being performed. These heat pumps use components and valves arranged in such a way that they are able to cool a space, heat a space, heat a liquid without affecting the temperature of the conditioned space, cool a space while heating a liquid, and defrost the outdoor coil using only the previously heated water as a heat source. During the defrost mode, hot water that is held in a storage tank is used to defrost the outdoor coil, without degrading the overall performance of the heat pump, but reducing the heating capacity. A refrigerant-to-water heat exchanger is used to provide energy to the refrigerant and allow it to melt the frost on the outdoor coil. The energy taken from the hot water in the system is easily and inexpensively replaced when the heat pump switches back into normal heating mode because it reduces the need for costly supplemental heat provided by electric resistance heaters. However, such a system would make no impact on the values of SEER or HSPF determined using the DOE test procedure. Consequently, DOE did not consider either of these defrost mechanisms as design options in the engineering analysis. DOE is not aware of any defrost mechanisms other than frost-less heat pumps or hot-water defrost that are currently in use on the market or in development that could have a potential benefit to rated SEER or HSPF.

3.4.6.2 Defrost Cycle Control

During a conventional heat pump defrost cycle some form of supplemental heating is needed to compensate for the reversal of the heat pump cycle. Usually electric resistance heaters are used to heat air inside the house while the defrost cycle occurs, and this type of heating is much less efficient than heating using the heat pump. Since the alternate heat sources are much less efficient, the efficiency of a heat pump can be increased by reducing the frequency and duration of the defrost cycles.

Defrost cycle control involves management of the initiation and termination of defrost cycles, and thereby the frequency and duration of defrost cycles. In conventional heat pumps defrost cycles are typically scheduled, and initiation and termination are timer-controlled. For this type of defrost cycle control, cycles are initiated at regular intervals and terminated after a fixed amount of time. Cycle frequency and duration are unrelated to actual frost conditions and are just based on estimations by the manufacturer. Under timer control, the frequency of defrost cycles is determined by the amount of time the manufacturer expects it to take for a large frost layer to develop in the worst-case scenario and by a cycle duration long enough to ensure complete defrost in the worst-case scenario. Timer-based defrost can lead to unnecessarily frequent and long defrost cycles.

Demand-based defrost cycles eliminate unnecessary defrost cycles. Demand-defrost heat pumps use sensors to measure outdoor coil and outdoor ambient conditions to determine when to initiate and terminate defrost cycles. A microprocessor examines and analyzes the compressor run time, ambient air temperature, and outdoor coil temperature, all of which determine the environment under which a defrost cycle should occur. The microprocessor is then able to determine when the defrost cycle should be initiated and when it should be terminated, reducing the overall number and duration of cycles and improving the efficiency of the heat pump.

A defrost cycle control system is set up to adapt from previous defrost cycles to attain improved defrost system operation at various outdoor temperature conditions. This technology can save energy annually by using a computer to run the defroster at the optimum time and optimum temperature based on the ambient temperature range. However, this system adds efficiency because it helps account for outdoor temperature variation. While the static nature of the DOE test procedure ambient conditions does not allow for increases in SEER or HSPF due to implementation of such a system, the test procedure contains a demand defrost credit for units with such controls, which allows for an increase to HSPF.

3.4.6.3 Three Stage Heat Pumps

Three stage or "triple capacity" heat pumps have an additional compressor to provide additional capacity at low ambient temperatures. This enables the heat pump to operate more efficiently than a two stage or single stage unit at lower temperature because a three stage heat pump requires less supplemental resistance heating. Rheem commented that equipment utility has not been proven sufficiently to consider them, while Ingersoll Rand stated that HSPF's for three stage heat pumps are not noticeably higher as tested according to the DOE test procedure. (CAC: Rheem, No. 76 at p. 11;CAC: Ingersoll Rand, No. 66 at p. 9) DOE agrees with these comments and believes there is no benefit to performance metrics according to the DOE test procedure, and therefore, will not consider three stage heat pumps further in the downstream analyses.

3.4.7 Solar Assisted Central Air Conditioners and Heat Pumps

One way to reduce the electrical consumption of an air conditioner or heat pump is through the use of solar energy. Solar panels are connected to the system and used to provide some of the power necessary for the unit to run. While solar-assisted systems are still partially dependent on conventional sources of electricity, they can be beneficial for reduction of peak demand electricity usage.

Solar assist does not increase the operating efficiency of the unit. While such solar-assisted units may reduce demand for electricity from the grid, the unit will still need the same amount of power regardless of the power source. Consequently, there is no benefit for SEER or HSPF ratings as tested by the DOE test procedure, and therefore, solar assist technology was not considered further in the analysis.

3.5 STANDBY MODE AND OFF MODE TECHNOLOGY ASSESSMENT

Section 310(3) of EISA 2007 amended EPCA to require that energy conservation standards address standby mode and off mode energy use. Specifically, when DOE adopts a standard for a covered product after July 1, 2010, it must, if justified by the criteria for adoption of standards in section 325(o) of EPCA, incorporate standby mode and off mode energy use into the standard, if feasible, or adopt a separate standard for such energy use for that product. (42 U.S.C. 6295(gg))

For air conditioners and heat pumps, the standby mode is in effect when the system is on but the compressor is not running, *i.e.*, the system is not actively heating or cooling but the compressor is primed to be activated by the thermostat. Thus, the standby mode for air conditioners functions during the cooling season and for heat pumps during both the cooling and heating seasons. Correspondingly, the off-mode generally occurs for air conditioners during all non-cooling seasons and for heat pumps during the "shoulder seasons" (*i.e.*, fall and spring) when consumers neither heat nor cool their homes. The SEER and HSPF metrics already account for standby mode but not off mode energy use because off mode energy use occurs outside of the seasons to which these descriptors apply. Incorporation of the off mode into these descriptors would mean that they would no longer be seasonal descriptors. Thus, because EPCA requires use of these descriptors for central air conditioners and heat pumps (see 42 U.S.C. 6291(22) and 6295(d)), it would not be feasible for DOE to incorporate off mode energy use into a single set of standards for central air conditioners and heat pumps. Therefore, DOE is adopting separate off mode standards that are maximum wattage (W) levels, which address such energy use. DOE also presents corresponding trial standard levels (TSLs).

3.5.1 Design Options Applicable to All Products

DOE identified the following design options as having the potential to reduce the electrical power consumption of a furnace operating in standby mode or a central air conditioner or heat pump operating in off mode:

1. Toroidal Transformer
2. ECM Control Relay

3.5.1.1 Toroidal Transformer

A toroidal transformer operates more quietly and efficiently than a typical laminated power transformer and has lower noise-inducing stray magnetic fields and smaller size and weight. A toroidal transformer has an annular core made of very tightly-wound, grain-oriented, silicon steel ribbons. The steel ribbons are arranged such that all their molecules are aligned with the direction of flux. This allows better performance than a traditional laminated transformer, in which unaligned molecules increase the core's reluctance, or capacity for opposing magnetic induction. [77]

Toroidal transformers also have virtually no air gap because they are made of continuously wound ribbon. Eliminating the air gap minimizes flux leakage, which is the principle source of power loss in a laminate transformer, such that nearly all flux is utilized. Additionally, toroidal transformers have a copper coating that reduces heat (*i.e.*, power) loss. These improvements in efficiency allow an up to 50 percent reduction in size and weight, such that they can be used in new, innovative applications. Overall efficiency of toroidal transformers is 90 to 95 percent.

Because transformers continue to supply power to the control board in all modes of operation, including standby mode, increasing their operating efficiency will reduce the furnace's standby electrical power consumption. However, although toroidal transformers have significant advantages over laminated transformers in efficiency, size, and weight, they are also more expensive to manufacture. Their tight, ring-shaped windings may make large scale manufacturing difficult, especially in contrast with the simple windings of a rectangular, laminated transformer design.

3.5.1.2 ECM Control Relay

During testing of standby and off mode components, DOE found that ECM motors and their associated controls consumed 3 watts in off mode, while PSC motors did not have any off mode power draw. Therefore, the ECM motor could be disconnected to further reduce a system's off mode power consumption. To accomplish this task, a control relay would need to be added to the circuit. A typical control relay activates a switch when current runs through it and when there is no current a spring holds the switch in the open position. However, DOE has not found any products which completely disconnect the ECM fan motor. Additionally, manufacturer feedback indicated that ECM motors are subjected to large currents upon start up and using a control relay to completely depower them could reduce the lifetime of the motors.

3.5.2 Standby Mode Design Options Applicable Only to Furnaces

3.5.2.1 Switching Mode Power Supply

DOE identified switch mode power supplies as having the potential to reduce the electrical power consumption of a furnace operating in standby mode. While linear power supplies regulate voltage supply to the dc circuit with a series element, switching mode power supplies (SMPS) do so in an alternative, more effective way. In a switching mode power supply, power handling electronics switch on and off (where 'on' means switch is closed and voltage drop is negligible and 'off' means the switch is open and current is negligible) with high frequency, effectively connecting and disconnecting the output (load) to the input source. Continuous power flow to the load can be maintained/controlled by varying the duty cycle or frequency of the SMPS.

Linear power supplies experience significant heat losses because they use resistance elements, which convert electrical energy to heat energy, to regulate power supply. By using a switch to control energy flow instead, switching mode power supplies avoid such heat losses and have much higher efficiency. SMPS do introduce transient losses that increase with frequency, but these losses are negligible in comparison with the energy saved.

Switching mode power supplies also allow the use of a smaller transformer than a linear power supply. This is because the size of the transformer (*i.e.,* the number of turns) is inversely related to power frequency. In one respect, switching mode power supplies are at a relative disadvantage in comparison to linear power supplies, which regulate voltage with greater precision and have simpler controls.

3.5.3 Off Mode Design Options Applicable Only to Central Air Conditioners and Heat Pumps

3.5.3.1 Thermostatically Controlled Crankcase Heaters

One option for reducing off mode power consumption is to thermostatically control the crankcase heater. While the added components will consume a small amount of additional power, the energy savings from more efficient use of the crankcase heater outweigh the added power consumption of these components. Manufacturer feedback indicated that in most units the crankcase heater turned on whenever the compressor cycled off. However, in some situations, the crankcase heater is not needed to prevent refrigerant migration or condensation in the compressor crankcase. A small disc thermostat on the unit to measure the outdoor ambient temperature, along with associated relay and wiring, can be used to regulate the crankcase heater does not come on unless needed.

Alternatively, the thermostat could be placed on the compressor itself and measure the shell temperature to determine when the crankcase heater is needed. However, DOE believes that scroll compressors are not currently equipped to accommodate a temperature sensor on the compressor shell, whereas reciprocating compressors are. By considering temperature sensors based on compressor shell temperature, DOE believes that manufacturers of scroll compressors would be unfairly impacted and that the market might be driven towards reciprocating compressors. Therefore, DOE decided not to include crankcase heaters, which are controlled based on compressor shell temperature in the analysis, and only considered crankcase heaters with a control strategy based on outdoor ambient temperature.

3.5.3.2 Self-Regulating Crankcase Heaters

Self-regulating or variable resistance crankcase heaters are similar in appearance to conventional crankcase heaters but are able to vary their resistivity as a function of outdoor ambient temperature. Varying the resistivity alters the current flowing through the crankcase heater, which in turn increases or decreases the power consumed by the crankcase heater. This variable resistivity is accomplished through a polymer core which expands as temperature increases, thereby disconnecting electrical pathways. Because they are self-regulating, these crankcase heaters do not require a thermostat to control them. However, there are potential additional energy savings through the pairing of a self-regulating crankcase heater with a thermostat. Additionally, a self regulating crankcase heater would have a lower power draw when used in conjunction with a compressor cover because of the thermal insulation provided by the cover, while a fixed resistance crankcase heater would have a constant power draw.

As part of the final rule analysis, DOE conducted off mode testing and found for heat pumps that the self regulating crankcase heaters did not reduce power consumption as compared to conventional crankcase heaters. Therefore, DOE believes that manufacturers will choose to install the conventional crankcase heater because it is cheaper and has a lower power draw than the self-regulating crankcase heater. Since the self-regulating crankcase heaters fail to improve efficiency according to the proposed off mode test procedure for heat pumps (75 FR 21224-31271), DOE only considered them further in the off mode analysis for air conditioners.

3.5.3.3 Compressor Insulation Cover

Some products have a cover over the compressor for noise reduction. While the main intent of these sound blankets is to minimize compressor noise, they provide a certain amount of thermal insulation to the compressor. This cover prevents the compressor shell from cooling as quickly when the compressor shuts off. If a variable resistance crankcase heater is used with this compressor cover, then the crankcase heater will have a lower power draw because of the thermal insulation provide by the cover. By allowing the crankcase heater to have a lower power draw, the cover helps to reduce the amount of off mode power consumption as measured by the proposed test procedure (75 FR 21224-31271).

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